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STANDARDIZATION PROCEDURE FOR TWO INSTRUMENTS FOR COLOR MEASUREMENT

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CLEMSON UNIVERSITY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A standardization method was developed to check that a color measuring instrument will perform satisfactorily and that measurements made with it are within acceptable tolerances. Four types of materials were selected to test the instrument: a white opal tile to check nominal 100% reflectance; an amber glass filter to check low and high photometric scale and the wavelength scale at mid range; a gray porcelain tile to check the reflectance scale at mid range; and a pair of polyester plastic samples to check that proper color differences are being measured and calculated. Two instruments were used in this study, a Hunterlab D54 spectrophotometer and a

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20. Diano Match-Scan spectrophotometer. Each was interfaced to a mini-computer for collecting data on the test materials. Based on statistical studies of the measurements made on the instruments, two slightly different computer programs were developed which provide guidance for the operator of the instrument through the standardization procedure and make comparisons of the current measured data to previously established norms and tolerances for the same material. The computer programs are "fail-safe" in the sense that the instrument cannot be used to perform routine tests unless all of the standardization criteria are met.

PREFACE

The work reported was performed as part of Phase II of a project to develop a color measuring system to be used for instrument judgment of color of textile fabrics procured by the Defense Department. The heart of the system is a spectrophotometer to be controlled by a computer that also performs required colorimetric calculations.

Phase I was limited to an evaluation of commercially available spectrophotometers, each with a small microprocessor. The evaluation was performed under Contract DAAK60-77-C-0093 by Rensselaer Polytechnic Institute and published as NATICK/TR-79/044. All three instruments evaluated were judged capable of meeting the color requirements. Because the system also must be capable of measuring infrared reflectance, however, one of the three instruments was dropped from further consideration in the system development.

The purpose of Phase II was to design the color measurement system to meet the needs of the program. One step in the design was the development of a mathematical means for expressing acceptability of slight deviations from standard shade. This work was performed under Contract DAAK60-78-C-0084 by Lehigh University and published as NATICK/TR-80-0036. A second step was development of a rigid system calibration procedure, which is the subject of this report. The work was performed under Contract DAAK60-79-C-0096 by Clemson University. The third step under Phase II was design and procurement of a prototype, two-unit system.

Support of the program was provided by the Manufacturing Testing Technology program. The Project Officer throughout both Phase I and Phase II was Alvin O. Ramsley; Alternate Project Officer was Therese R. Commerford.

The project officers acknowledge with thanks the constructive suggestions made by the Committee on Color Measurement of the National Research Council. Committee members are David L. MacAdam, Chairman, Ellen C. Carter, Franc Grum, Robert F. Hoban, Michael E. Breton and John J. Hanlon.

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STANDARDIZATION PROCEDURE FOR TWO INSTRUMENTS FOR COLOR MEASUREMENT

Introduction

The U.S. Army Natick Research and Development Laboratories entered into a contract with Clemson University to have a method developed for the standardization of color measuring instruments. This is one part of the longer range program to evolve an inspection procedure for the acceptance of the color of military fabrics through instrumental measurement rather than by visual estimation. Although there are several problems to be solved before a reliable procedure is achieved, two of the major aspects of the project have been investigated under contract and reported separately. In one of these contracts Billmeyer and Alessi addressed the general reliability of commercial color instruments, and in the other one Allen and Yuhas developed the mathematics of the color acceptability criteria.[1,2] The present work covers a third aspect which involves the technique that would be used to assure reliability of the instrumental measurement through proper calibration.

Instrumentation used in study

Two instruments were used to develop and test the standardization procedure. Both instruments are commercially available and had been investigated in an earlier contract and had been found in the main to be suitable. One instrument is the Hunter D54 spectrophotometer (Christie and McConnell, 1977) and the other is the Diano Match-Scan spectrophotometer.[3] Except for the fact that both instruments involve integrating spheres and diffuse polychromatic illumination, the optical arrangement of the two is quite different. Nevertheless, the measurement data obtained in this study with both instruments were quite comparable although they were not exactly interchangeable. No attempts were made to introduce adjustments to compensate for these small differences in results.

The Hunter spectrophotometer was loaned to Clemson by Natick Laboratories for the purpose of this study. It consisted of three interconnected units: a measuring head, power supply, and a microprocessor push-button controller. In order to collect the large amount of statistical data required in this work, the instrument controller was interfaced to a General Automation SPC-16/45 minicomputer. On occasions when graphical data were needed, the spectrophotometer was connected to a Tektronik 4662 plotter. The SPC-16 was programmed in Fortran to aid in the data collection and the standardization test procedure.

1. F. W. Billmeyer, Jr. and P. J. Alessi (1979, "Assessment of Color-Measuring Instruments for Objective Textile Acceptability Judgement" Technical Report NATICK/TR-79/044, U.S. Natick Research and Development Command, Natick, MA 01760, March 1979.

2. E. Allen, and B. Yuhas (1980), "Investigations to Define Acceptability Tolerance Ranges in Various Regions of Color Space," Technical Report, NATICK/TR-80/036, U.S. Army Natick Research and Development Command, Natick, MA 01760, September 1980.

3. J. S. Christie, and G. McConnell, Color 77, p. 309, Adam Hilger Ltd., Bristol, England, 1977.

The Diano Match-Scan spectrophotometer is part of an integrated instrument computer system called the Match-Mate 3000. The instrument is entirely computer-controlled which means that special test programs were written in Fortran around operating software that was furnished by the manufacturer. The Tektronik 4662 plotter was also interfaced to the Match-Mate 3000 system for drawing special graphs.

Basic calibration methods

Spectrophotometric reflectance data are the basic measurements used for calculating color difference values which in turn express the acceptability of the color of test materials compared to established standards. Therefore, it is necessary to evolve a method that would establish with a fair degree of certainty that the instrumental measurement is reliable in order that a high degree of confidence can be placed on tests performed with the equipment. Such a premise infers that the instrument is set up for operation and then checked according to prescribed methods. It must be relative to some accurately known set of data. If these data are based on fundamental measurement of wavelength and spectral power, then this is an absolute method. Alternatively, the values of a set of calibrating materials can be known relative to a master set of similar materials; when the instrument is performing satisfactorily, the results obtained on a specific set of materials will be within specified tolerances. This is a relative calibration method. In this application, long term repeatability of measurements of a given instrument and reproducibility of measurements between locations are of paramount importance, therefore, the relative calibration method is followed in the present study.

Wavelength scale calibration has been done for many years on several commercial spectrophotometers using the well-known absorption maximum of the Corning 5120 didymium glass. Gibson, and Keegan found that several maxima can be used with spectrophotometers having a constant bandwidth in the range between 2 and 10 nm; this offers a method for checking spectrophotometers that have such resolution.[4] Although the Match-Scan can be calibrated with didymium, this procedure is inappropriate for the D54 instrument which has a bandwidth that changes from 12 nm at 400 nm to 18 nm to 700 nm, making the didymium filter less suited to this purpose. This is shown in Figure 1. Venable and Eckerele (1979) have described a more advanced method for wavelength calibration with a didymium filter which is suitable for any wavelength bandpass.[5]

4. K. S. Gibson, and H. J. Keegan, J. Opt. Soc. Am. 31, 462 (1941).

5. W. H. Venable, Jr., and K. L. Eckerle, (1979), "Didymium Glass Filters for Calibrating Wavelength Scale of Spectrophotometer-SRM 2009, 2010, 2013 and 2014," NBS Special Publication 260-66. National Bureau of Standards, Washington, DC 20234.

An alternative method for wavelength calibration was described by Van den Akker and adapted for the D54 instrument by Stanziola et al.[6,7] It requires pairs of glass filters having spectrophotometric curves that cross at a determinable wavelength. In the region of the crossing, it is best that the transmission curves be approximately linear. Two sets of filters have been used to check the wavelength scales around 440 nm and 590 nm which presumes to cover the limits of the visible spectrum. The Van den Akker method is applicable to both the D54 and Match-Scan; curves obtained with each instrument are shown in Figures 2 and 3.

There are caveats to the crossing-filter method. Individual sets of filters give particular wavelength crossings which are dependent as well upon bandwidth and instrument geometry. Different values for the intersection wavelength will also be obtained depending upon what wavelength increment is used to interpolate among the transmission measurements for each pair of filters. The crossing wavelength can be computed with data from any wavelength interval according to the following formula:

$$X = I\,(t_3 - t_1)/(t_2 + t_3 - t_1 - t_4) + W$$

where,

X is the crossing wavelength

I is the wavelength increment

t_1, t_2 are the transmittances for the first filter at wavelength, W, and wavelength, W + I, respectively

t_3, t_4 are the transmittances for the second filter at the same wavelengths as the first filter

W is the first wavelength

A 10-nm increment is preferred because it is a normal mode of operation for the D54 instrument and this makes for a convenient procedure. Hunterlab makes their determinations at 1-nm intervals, which give slightly more variable data (see below) than with 10-nm intervals. There is a small difference in the crossing wavelength dependent upon the wavelength increment, but as long as the same procedure is used at all times, the resulting values should be consistent.

Another method based on mercury emission lines is suited to the Match-Scan instrument but not the D54. The Match-Scan is provided with a Stand-Alone

6. J. A. Van den Akker, J. Opt. Soc. Am. 33, 257 (1943).

7. R. Stanziola, B. Momiroff, and H. Hemmendinger, Color Research Application 4, 36 (1979).

Program (SAP) which allows for single-beam radiometric measurements at 0.2-nm intervals. The output of a mercury arc lamp can be scanned around the emission peaks at 404.7, 435.7, 546.1, 557-578 to determine whether the instrument wavelength scale is correct. This has been done with the Match-Scan and the results are shown in Figure 4. Although the instrument has not been reset to the correct wavelength, the wavelength error is repeatable over a six-month period indicating that reproducible measurements can be achieved.

The D54 is routinely calibrated by the manufacturer, Hunterlab, using a series of filters of known spectral transmittance values for corresponding wavelengths.[8] Diano, on the other hand, calibrates the Match-Scan using the didymium filter absorption points. However, the purpose of this procedure is to recognize whether an instrument is performing in the same way that it had been when it was put into service. To that end a simple wavelength check is made with the transmittance of an anber filter at about the middle of the visible spectral range.

Several methods have been cited for wavelength checking but there are not generally accepted methods for establishing the validity of the photometric (reflectance or transmittance) scale for a spectrophotometer. In cooperation with the National Bureau of Standards we have developed a set of four neutral gray glass filters of ascending transmittances from about 0.5% to 31%. These were measured on the NBS high-accuracy spectrophotometer at 511 nm, which is in an area of relatively flat transmittance.[9] Since the high-accuracy spectrophotometer will give transmittance values at least more precise than any commercial instrument, it was felt that these filters would serve as a good reference for both instruments in this study.

The measurements obtained on the instruments are given in Tables 1 and 2. It will be noted that 1-nm data obtained with the D54 are slightly less consistent than data obtained with the Match-Scan. For reasons not known, these data are not in keeping with the 10-nm data obtained on the D54 in other parts of this study. Although the photometric readings on both instruments are not equal to those of the NBS, repeat tests done weeks apart indicate that the departure from the Bureau's values remains constant. One can presume from this that either the method of measurement in the commercial instruments produces a specific bias or that the normal standardization methods for these instruments do not compensate for nonlinearity in the photometric scale. Nonetheless, consistency of results is the overwhelming requirement.

Routine calibration

The calibration method which was finally developed as a result of this investigation considered that the following criteria were important:

a. Physical samples should be measured on the instrument and should be stable, easily cleaned, and of a convenient size.

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8. See Reference 3.

9. See Reference 5.

b. Measurements should check the performance of the instrument as for wavelength reliability as well as low range (below 5%) and high range (above 70%) photometric response.

c. Measurements should also check the 100% line and the mid-scale correction in the reflection mode.

d. A final check should be made of the ability of the instrument and computer system to give reproducible color difference values on a pair of samples of known color difference.

e. Backup calibration materials should be available to check the instrument wavelength if there are indications of wavelength uncertainty in the routine test.

These objectives were satisfied by selection of the following materials:

a. A white opal glass, 50 mm square by 10 mm thick which is covered on back and sides with black paper. See Figures 5 and 6.

b. A Corning 3307 Signal Yellow filter, 50 mm square by 2.3 thick. See Figures 7 and 8.

c. A gray porcelain enamel plaque, 10.7 cm square. See Figures 5 and 6.

d. A pair of tan polyester gelcoat plaques, 7.8 mm square. See Figures 9 and 10.

e. Four glass filters for wavelength checking. Each is 50 mm square. These filters were obtained through Hunter Associates Laboratory (the Corning description is only given for reference).

Blue-Corning 5851, 2.8 mm thick
Green-Corning 4445, 5.0 mm thick
Yellow-Corning 3387, 3.0 mm thick
Red-Corning 2424, 3.1 mm thick

Six sets of these calibration materials were obtained and checked for similarity. Only one set of materials was used throughout this study; individual values for the remaining five sets are given in Table 3 of this report.

In order to establish the range of expected values that would be obtained when the calibrating materials are measured on each instrument, two Fortran programs were written to assist in the collection and evaluation of the resulting data. The programs are the same in principle, but since each instrument operates differently and is interfaced to its own computer, small changes were made to fit each case. QMSTAT is the program used with the Diano Match-Scan and its Digital Equipment Company LSI-11 computer and QMSTA1 is used with the Hunter D54 spectrophotometer and the General Automation SPC-16 computer.

The procedure used for the calibration samples with the Match-Scan, made it simple to measure the samples in sequence:

Opal glass
Amber filter
Gray porcelain enamel tile
Standard tan plastic
Sample tan plastic

Each sample was carefully washed with a 1% solution of Sparkleen (Fisher Scientific Company), rinsed with distilled water and carefully dried with Kimwipes. This was done before every measurement.

In the case of the D54 instrument, a procedure that includes instrument setup was added:

Set up D54 for transmittance:

a. Press "TRANS" button
b. Block beam with black cardboard and press "ZERO"
c. Insert white tile and press "STDZ"

Measure Amber filter

Set up D54 for reflectance:

a. Press "R-SIN" button
b. Place black trap over port and press "ZERO"
c. Place white tile over port and press "STDZ"
d. Place gray tile over port and press "STDZ"

Measure Opal glass
Measure Gray porcelain enamel tile
Measure Standard tan plastic
Measure Sample tan plastic

Both QUMSTAT and QMSTA1 programs provide the necessary prompting so that the operator follows the proper sequence. In the QMSTAT program the paired white opal glasses are assumed to be approximately matched, and all of the subsquest measures are corrected to a value which compensates for any mismatch. A set of measurements and calculations for both instruments are given as Figures 11 and 12. Note that all spectral data lists the results of a single measurement, the average of two measurements and the average of ten measurements. Based on these data and the calculated standard deviation (sigma), it was concluded that the average of two measurements was suitable. Since we were not able to actuate the D54 through the program on the SPC-16 computer, we were obliged to operate the spectrophotometer through the keyboard and collect the resulting data through and ASCII interface to the computer. This was accomplished by first pressing the "READ" button; then when the "BUSY" light went out, the "10 NM" button on spectrophotometer console and the "RETURN" on the computer keyboard were pressed simultaneously.

A "PAUSE" was built into the computer program to allow for these operations to take place. Figure 12 shows that the ten repeat measurements were made with a PAUSE between each set. Analogous data to those shown for the Match-Scan in Figure 11 were obtained for the D54 instrument. In preparing Figure 12, the intermediate PAUSE statements have not been shown.

Working Calibration Method

The statistical studies with the two instruments were carried on for several months to establish a long term record of performance with the calibrating materials. Based on these experiments, two new programs QMSTAN for the Match-Scan and QMSTANH for the D54 were written to serve as a "fail-safe" calibration procedure that will not permit operation of the instrument if it fails within the limits set for each material. Again there are some differences between the instruments in the procedure itself as well as the specific limits set for each material. Figures 13 and 14 give a diagram of the information needed to effect the calibration of each instrument. Figure 15 shows a set of data obtained with the Match-Scan and Figure 16 shows a set of data obtained with the D54 spectrophotometer.

Observations

Table 3 summarizes the values obtained with each set of materials that are recommended for standardization of any spectrophotometer similar to the D54 or Match-Scan. The tolerances given in the Table reflect the experience obtained from this study. In the main, the tolerance that were determined for acceptable instrument performance in the QMSTAN and QSTANH programs are similar, since both instruments performed in a comparable manner. The data that were obtained on Set #1 were specifically determined on both instruments at 76° ± 1°F. All of the other data were obtained on the Match-Scan.

Slightly larger tolerances are given for the D54 than the Match-Scan, which allows for the change in transmittance when the D54 is operated at 84°F. Experiments were repeated twice with the temperature in the Clemson Color Science Center laboratory raised to 84°F. When this was done, the transmittance of the amber filter as measured by the D54 was slightly lower than typical results obtained at 76°F. The measurements performed on the Match-Scan at the same time did not show any difference between the two temperatures. If one can assume that the transmittance of the amber filter is approximately linear between 520 and 530 nm, 1% change in transmittance is equivalent to a 0.63 nm wavelength change. Therefore, the tolerance of 0.3% is equivalent to about 0.19 nm for the D54 and 0.13 for the Match-Scan. No statistically significant color differences were determined for the twn plastic samples when the data obtained at 76°F were compared to those at 84°F.

This document reports research undertaken in cooperation with the US Army Natick Research and Development Command under Contract No. DAAK60-79-C-0096 and has been assigned No. NATICK/TR-82/024 in the series of reports approved for publication.

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Table 1. Transmission Data on NG-9 and NG-3 Neutral Gray Filters Calibrated by National Bureau of Standards at 511 nm; measurements at 1-nm intervals.

SAMPLE NAME?
NG-9 NBS Value 0.807%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

Matchscan

W/L	%R
505.0	0.82
506.0	0.82
507.0	0.82
508.0	0.82
509.0	0.81
510.0	0.82
511.0	0.81
512.0	0.82
513.0	0.81
514.0	0.82
515.0	0.82
516.0	0.82
517.0	0.82
518.0	0.82
519.0	0.82
520.0	0.82

CONTINUE? [Y/N] Y

D 54

TRANSMITTANCE

505	.83
506	.84
507	.82
508	.83
509	.84
510	.81
511	.87
512	.84
513	.81
514	.86
515	.83
516	.84
517	.80
518	.80
519	.86
520	.82

SAMPLE NAME?
NG-3 NBS Value 2.693%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

Matchscan

W/L	%R
505.0	2.74
506.0	2.74
507.0	2.74
508.0	2.73
509.0	2.74
510.0	2.74
511.0	2.74
512.0	2.74
513.0	2.74
514.0	2.74
515.0	2.74
516.0	2.75
517.0	2.74
518.0	2.75
519.0	2.75
520.0	2.76

CONTINUE? [Y/N] N

D 54

TRANSMITTANCE

505	2.74
506	2.77
507	2.72
508	2.76
509	2.73
510	2.73
511	2.75
512	2.74
513	2.74
514	2.76
515	2.72
516	2.78
517	2.75
518	2.73
519	2.75
520	2.73

Table 2. **Transmission Data on NG-4 and NG-5 Neutral Gray Filters Calibrated by National Bureau of Standards at 511 nm; Measurements at 1-nm intervals.**

SAMPLE NAME?
NG-4 NBS Value 4.384
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

Matchscan

W/L	%R
505.0	4.49
506.0	4.48
507.0	4.48
508.0	4.47
509.0	4.48
510.0	4.47
511.0	4.47
512.0	4.47
513.0	4.47
514.0	4.47
515.0	4.49
516.0	4.49
517.0	4.50
518.0	4.51
519.0	4.52
520.0	4.53

CONTINUE? [Y/N] Y

D 54

TRANSMITTANCE

505	4.51
506	4.52
507	4.44
508	4.50
509	4.49
510	4.48
511	4.50
512	4.47
513	4.49
514	4.49
515	4.47
516	4.54
517	4.53
518	4.47
519	4.51
520	4.48

SAMPLE NAME?
NG-5 NBS Value 31.145%
AVERAGE READINGS ? [Y/N] Y
NO. OF READINGS TO AVERAGE? 2

Matchscan

W/L	%R
505.0	31.47
506.0	31.47
507.0	31.47
508.0	31.45
509.0	31.48
510.0	31.46
511.0	31.47
512.0	31.46
513.0	31.47
514.0	31.48
515.0	31.50
516.0	31.51
517.0	31.53
518.0	31.55
519.0	31.55
520.0	31.61

CONTINUE? [Y/N] Y

D 54

TRANSMITTANCE

505	31.59
506	31.61
507	31.61
508	31.65
509	31.62
510	31.65
511	31.70
512	31.69
513	31.64
514	31.67
515	31.63
516	31.69
517	31.59
518	31.69
519	31.62
520	31.66

Table 3. Measured Values for Calibration Materials.

		Set Number 1				Mean T or R in % - other sets					
		Match-scan		D54		#2	#3	#4	#5	#6	
	Mean Length	Mean T or R	Tolerance	Mean T or R	Tolerance						
White Tile	540	100.02*	±0.07	98.36	±0.10	100.08	100.17	99.96	100.03	99.96	%
Amber Filter	420	3.50	±0.03	3.48	±0.03	3.81	3.57	3.39	3.02	2.54	%
	520	39.15	±0.12	38.68	±0.18	40.21	39.36	38.96	37.66	35.86	%
	660	79.97	±0.12	80.20	±0.12	80.06	79.81	79.61	79.19	78.43	%
Gray Porcelain Tile	540	43.90	±0.10	42.96	±0.10	44.66	44.57	43.96	44.33	45.03	%
Tan Plastic -		Mean	Tolerance	Mean	Tolerance	Mean	Mean	Mean	Mean	Mean	
CIEL* a* b* 1976		1.89	±0.05	1.88	±0.05	2.06	1.98	1.97	2.10	1.90	Delta E
	Wave Length										
Filter Pair											
Dk Blue - Yellow	441.3					441.3	438.9	441.3	440.4	442.2	nm
Red-Blue Green	590.1					590.1	589.3	590.1	591.0	589.6	nm

*Sample versus Standard tile

Revised July 2, 1981

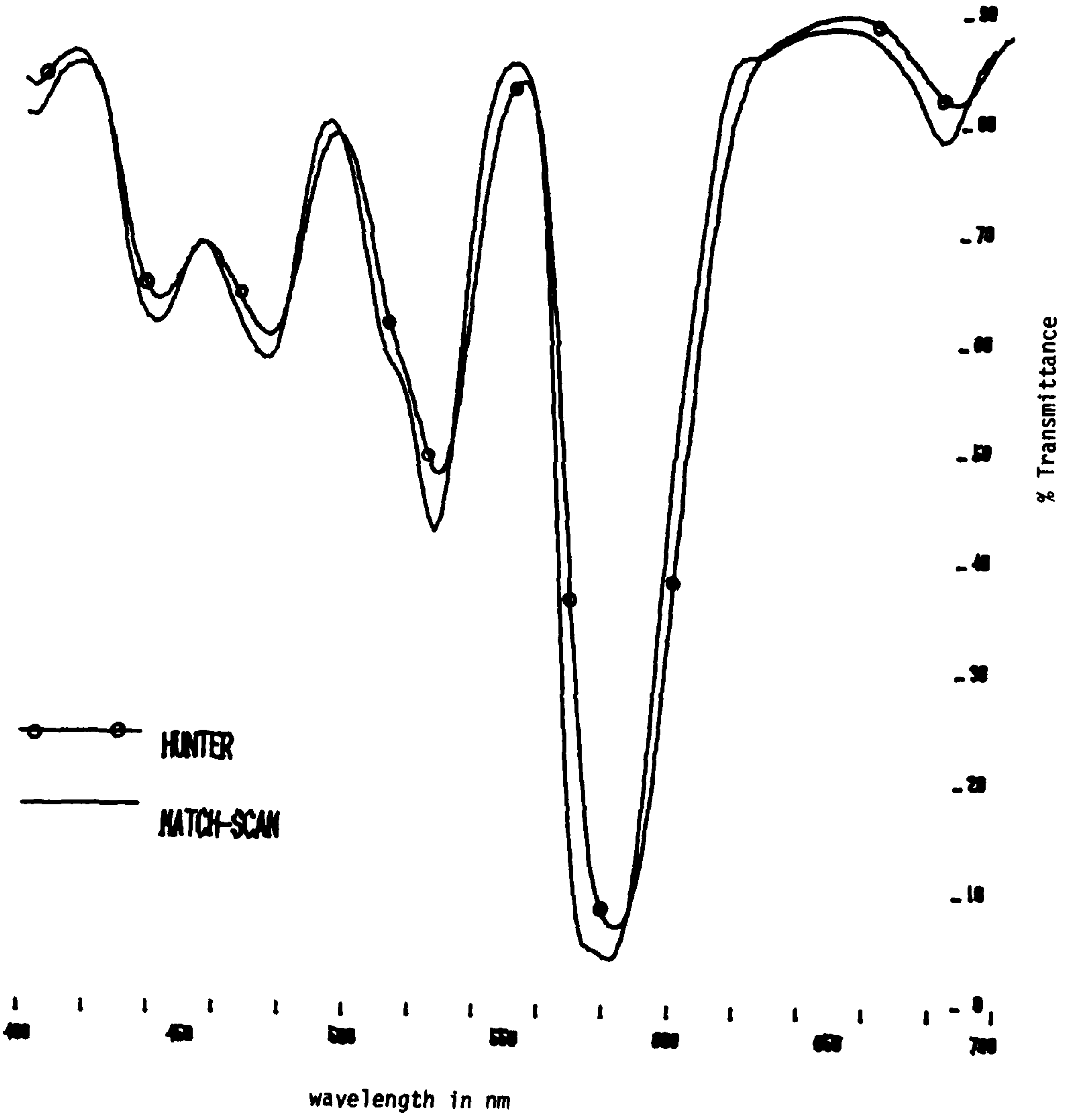

Figure 1. Transmission curves of didymium filter for Hunter D54 and Match-Scan instruments.

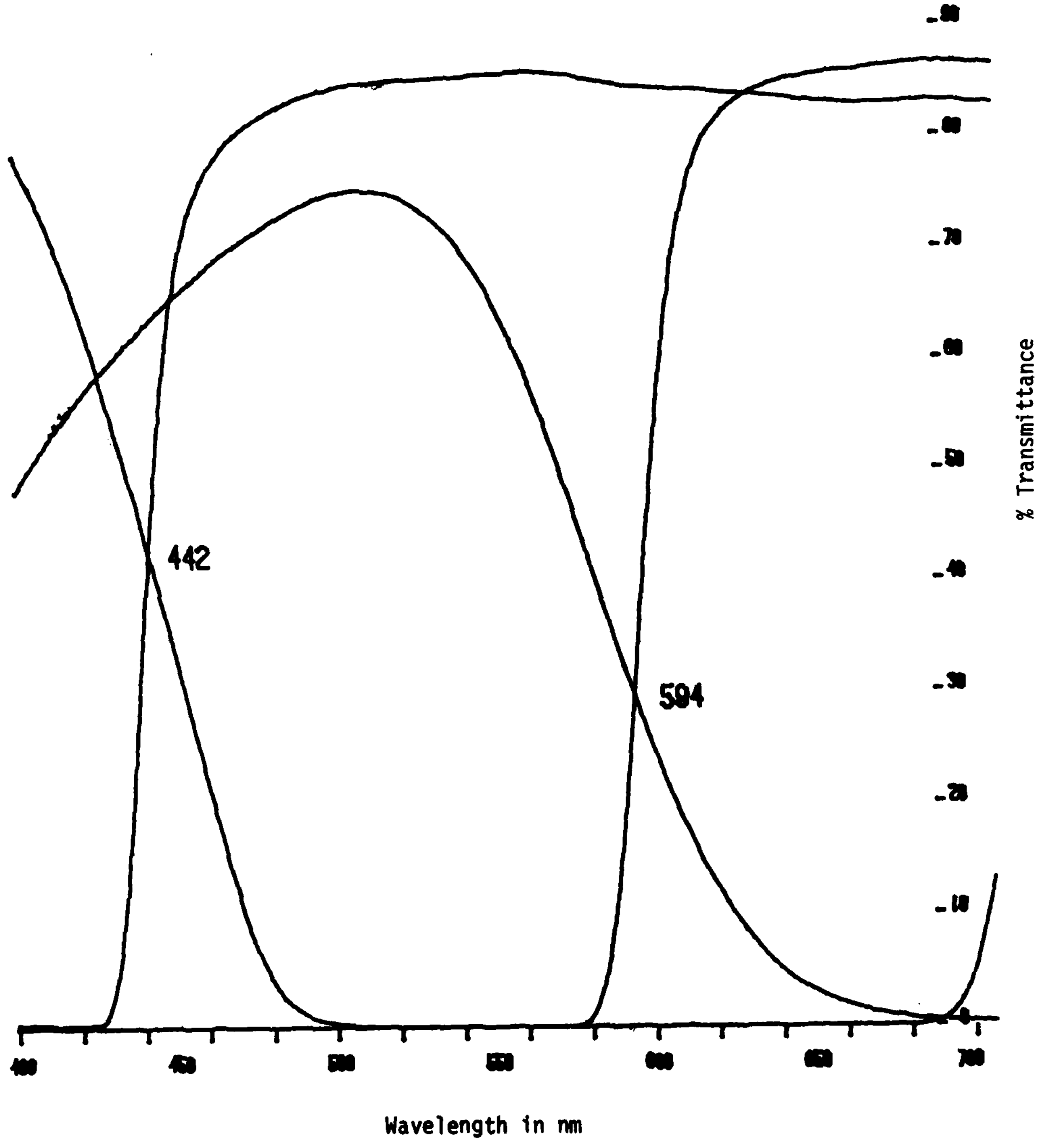

Figure 2. Match-Scan wavelength calibrating filter transmission curves.

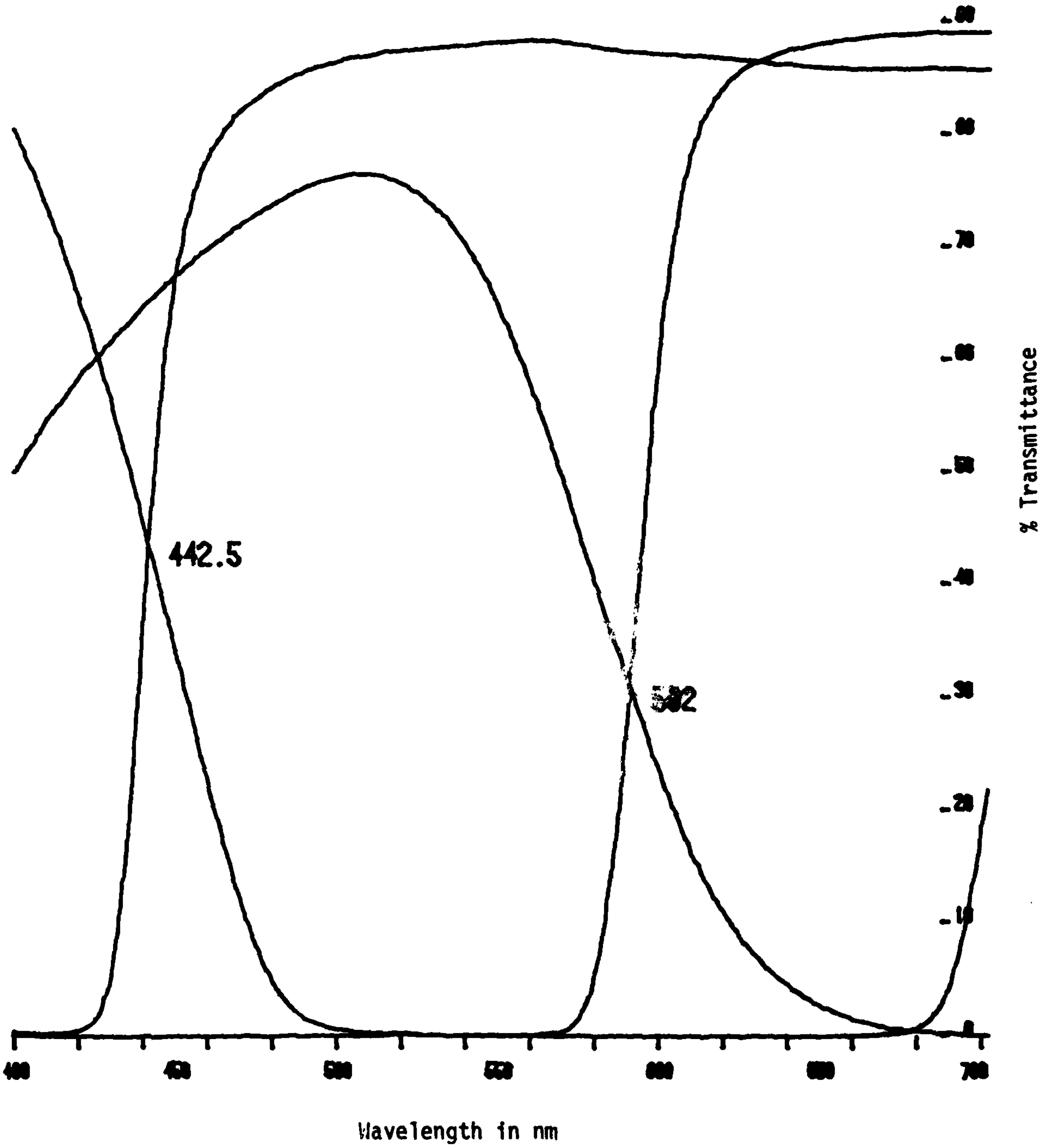

Figure 3. Hunter D54 wavelength calibrating filter transmission curves.

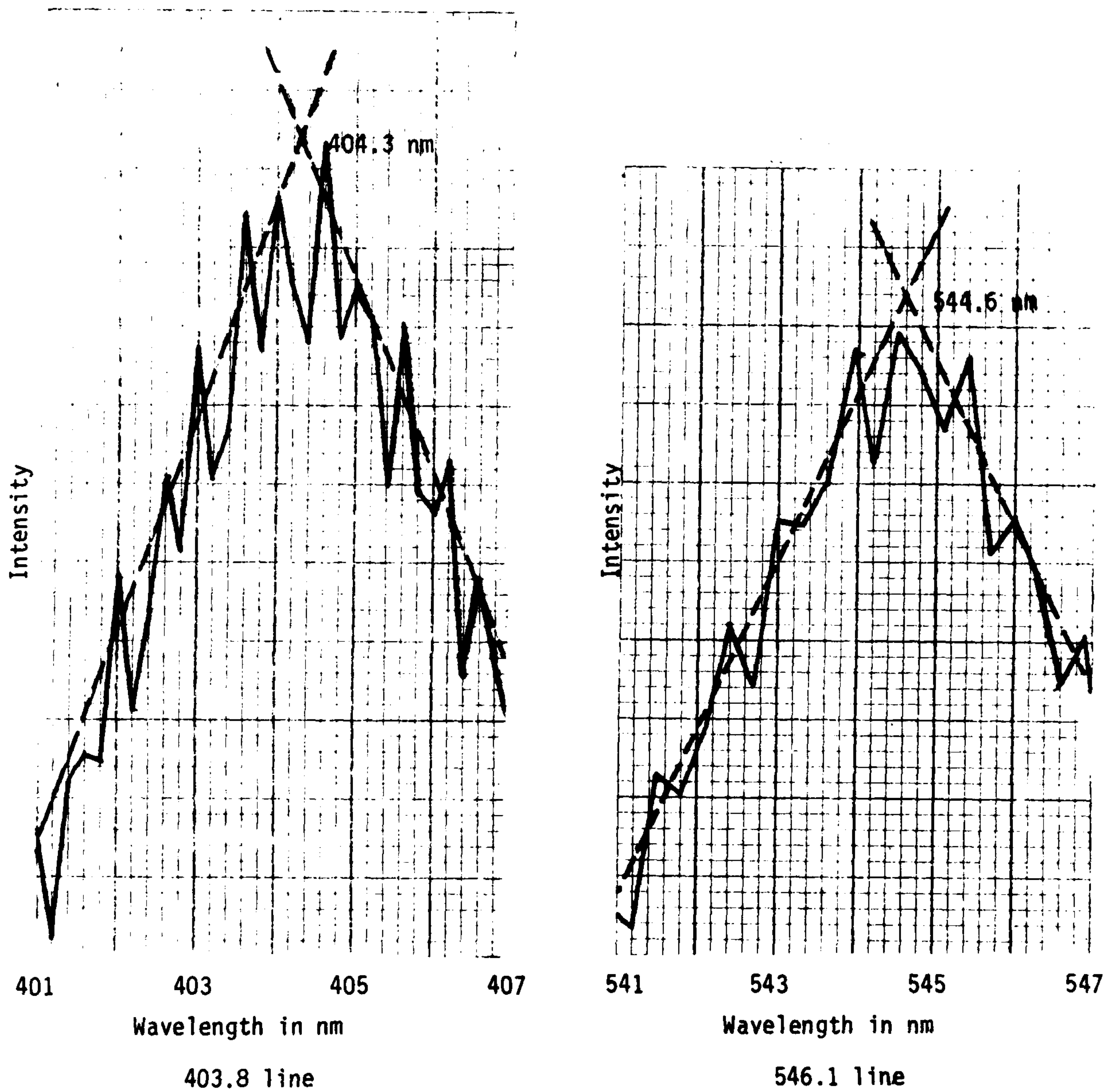

Figure 4. Mercury emission lines on the Match-Scan instrument.

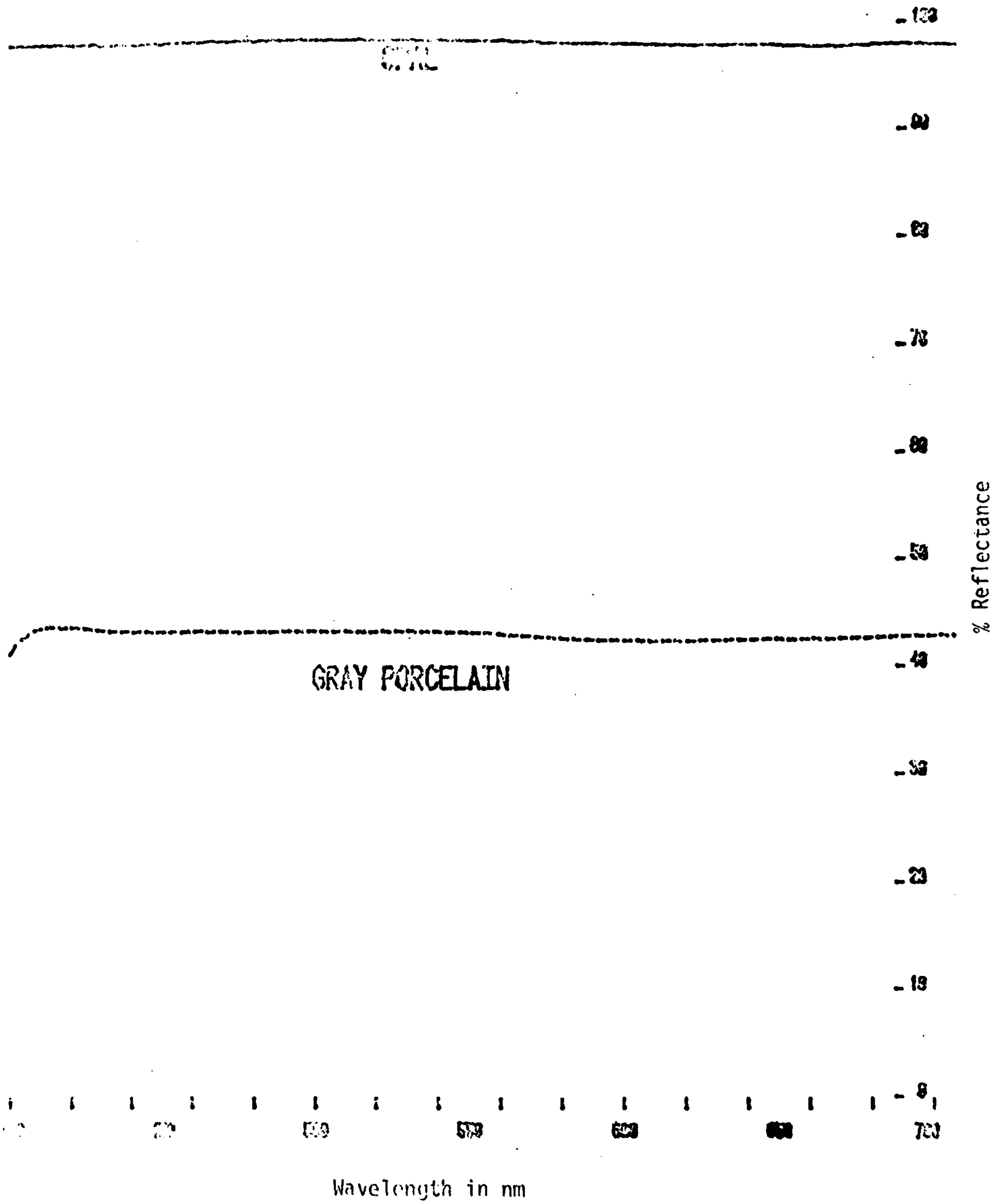

Figure 5. Reflectance of opal and gray porcelain tiles with Match-Scan.

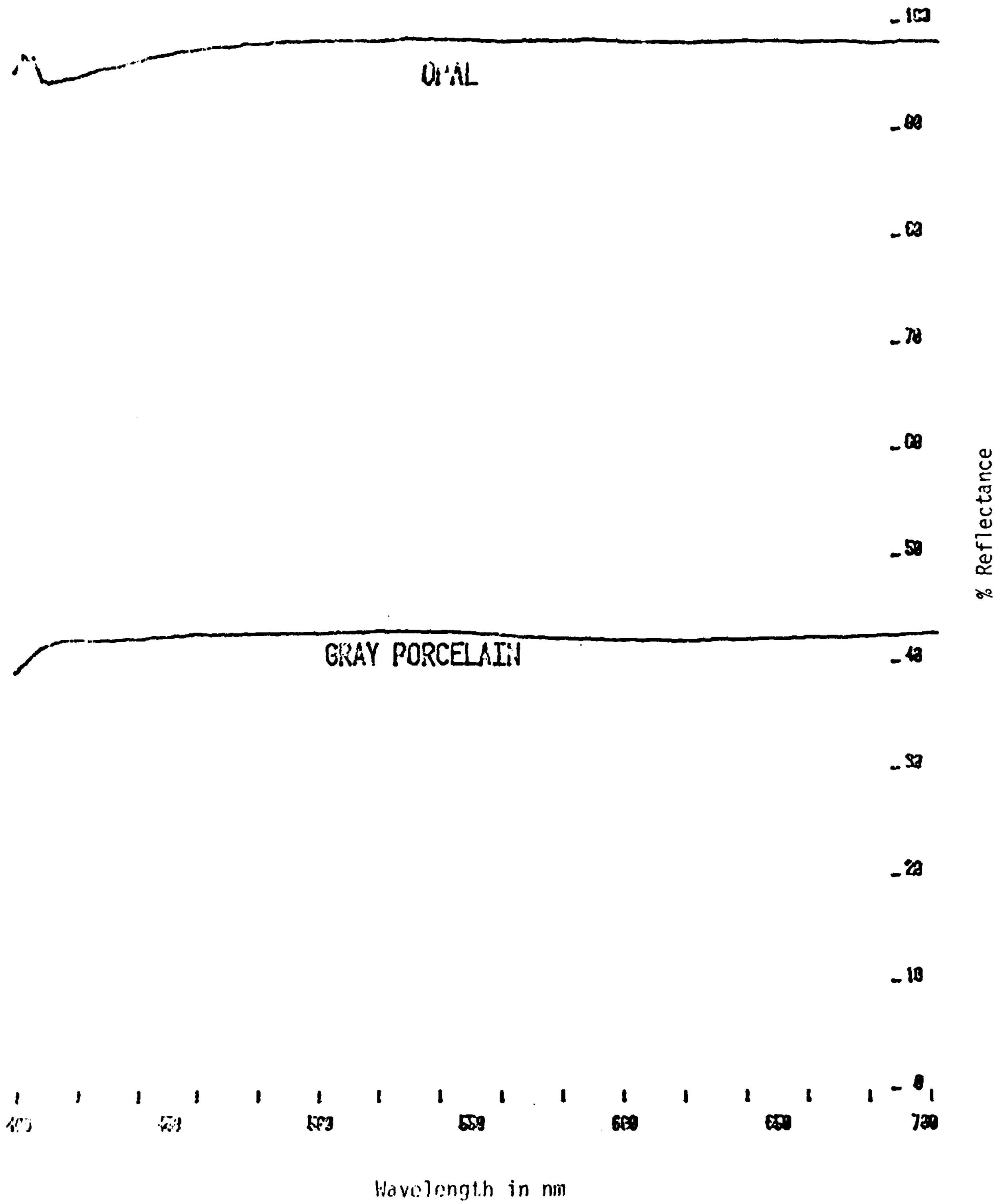

Figure 6. Reflectance of opal and gray porcelain tiles with Hunter D54.

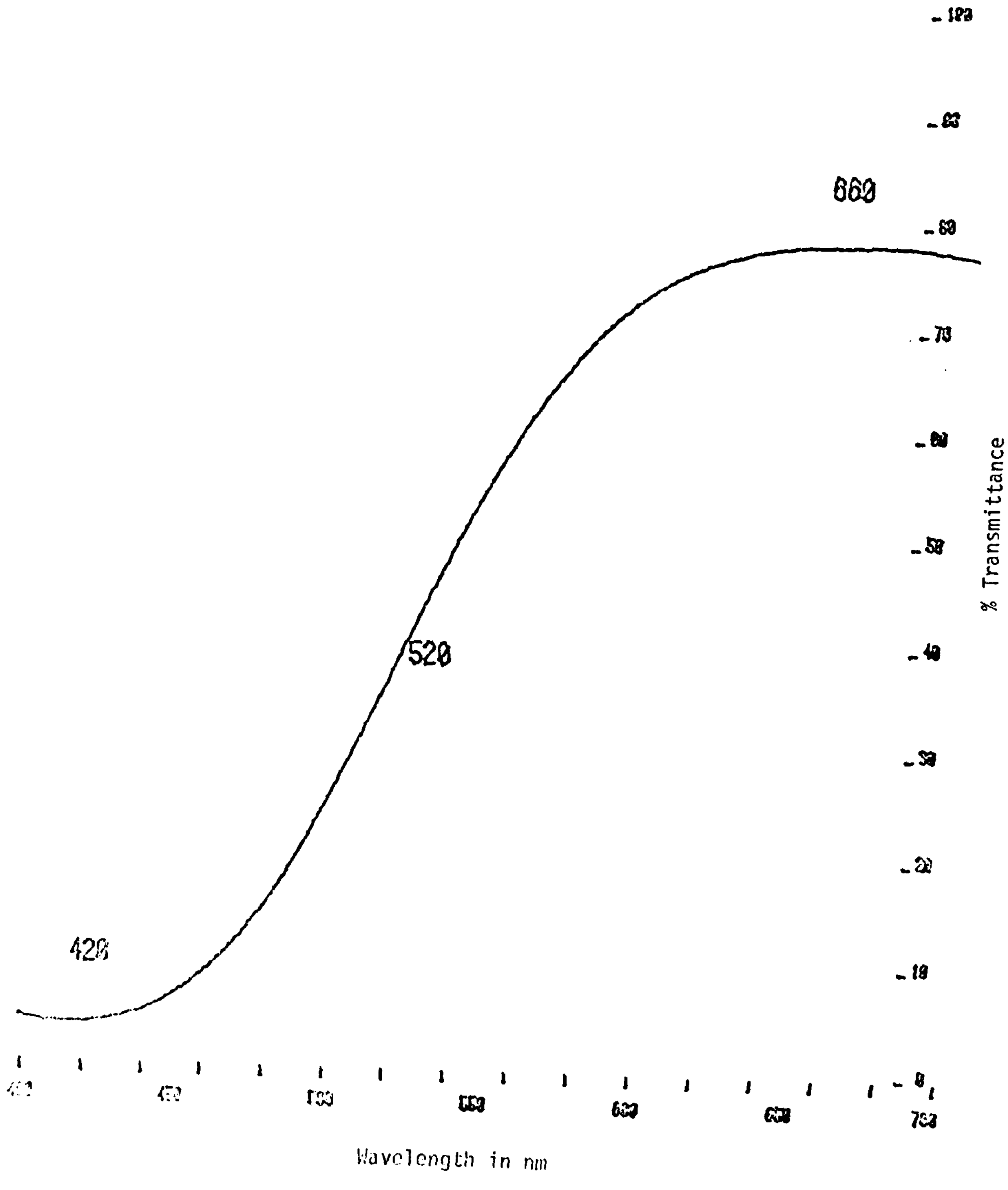

Figure 7. Transmittance of amber filter with Match-Scan.

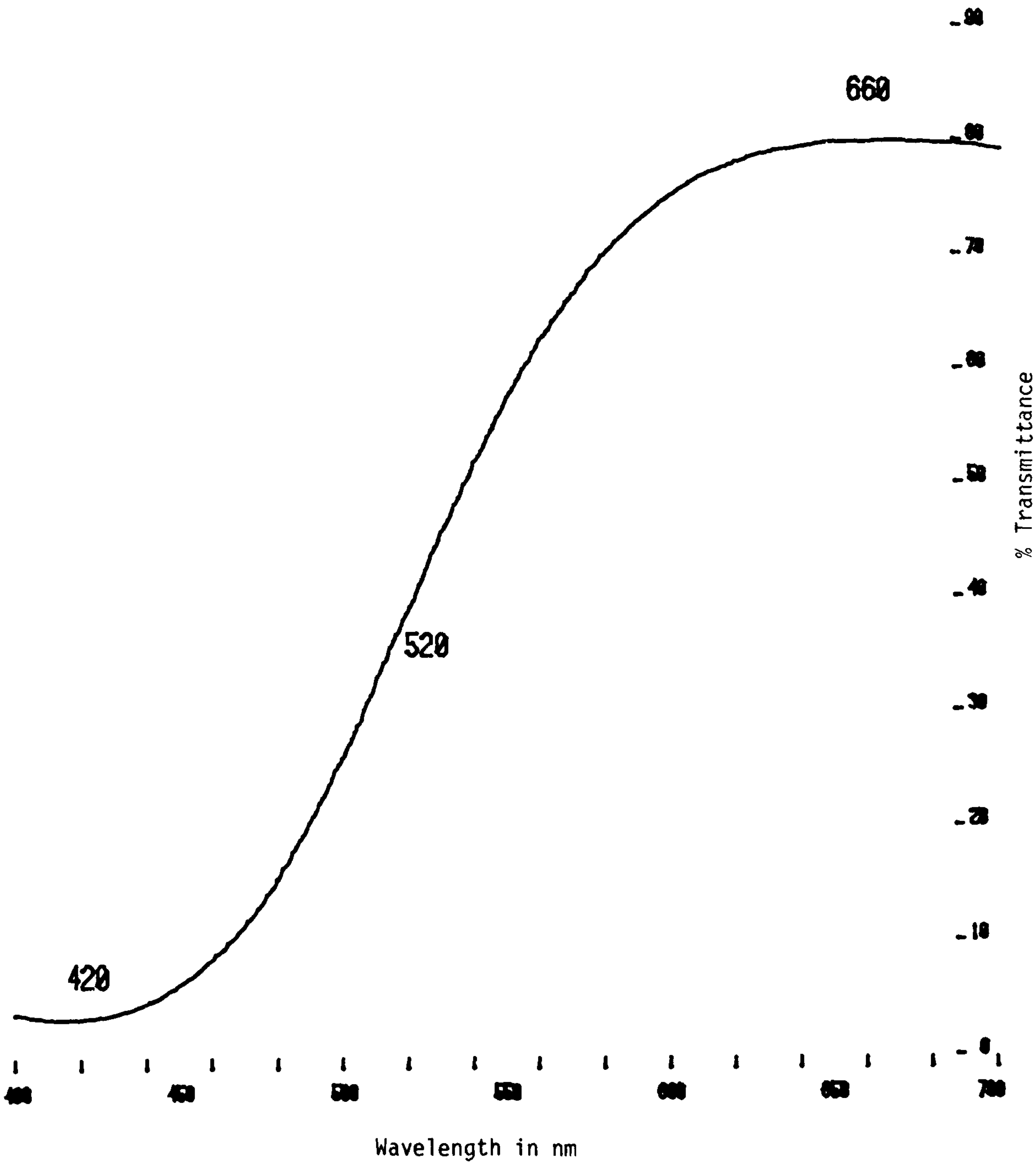

Figure 8. Transmittance of amber filter with Hunter D54.

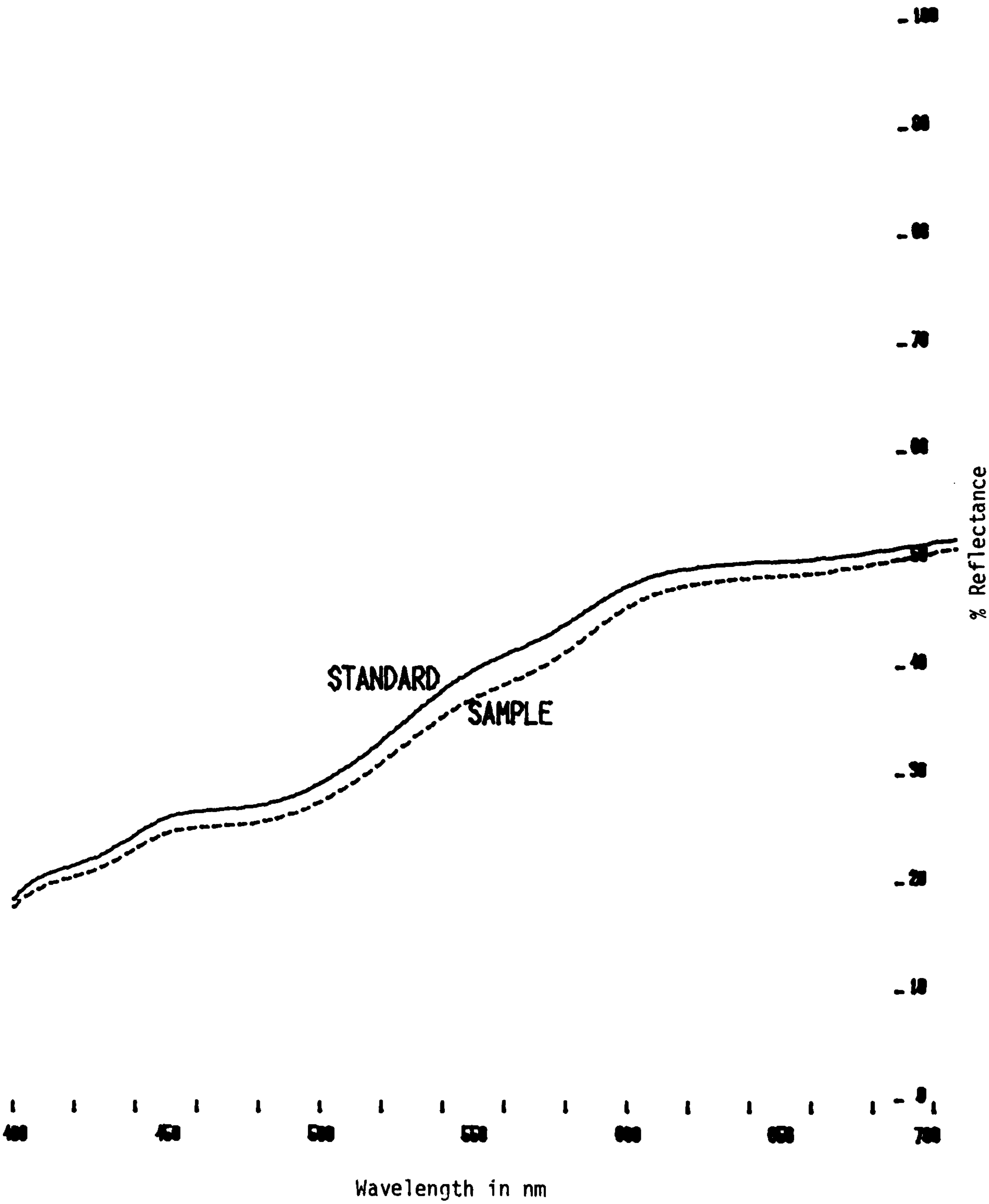

Figure 9. Reflectance curves of a pair of tan specimens with the Match-Scan.

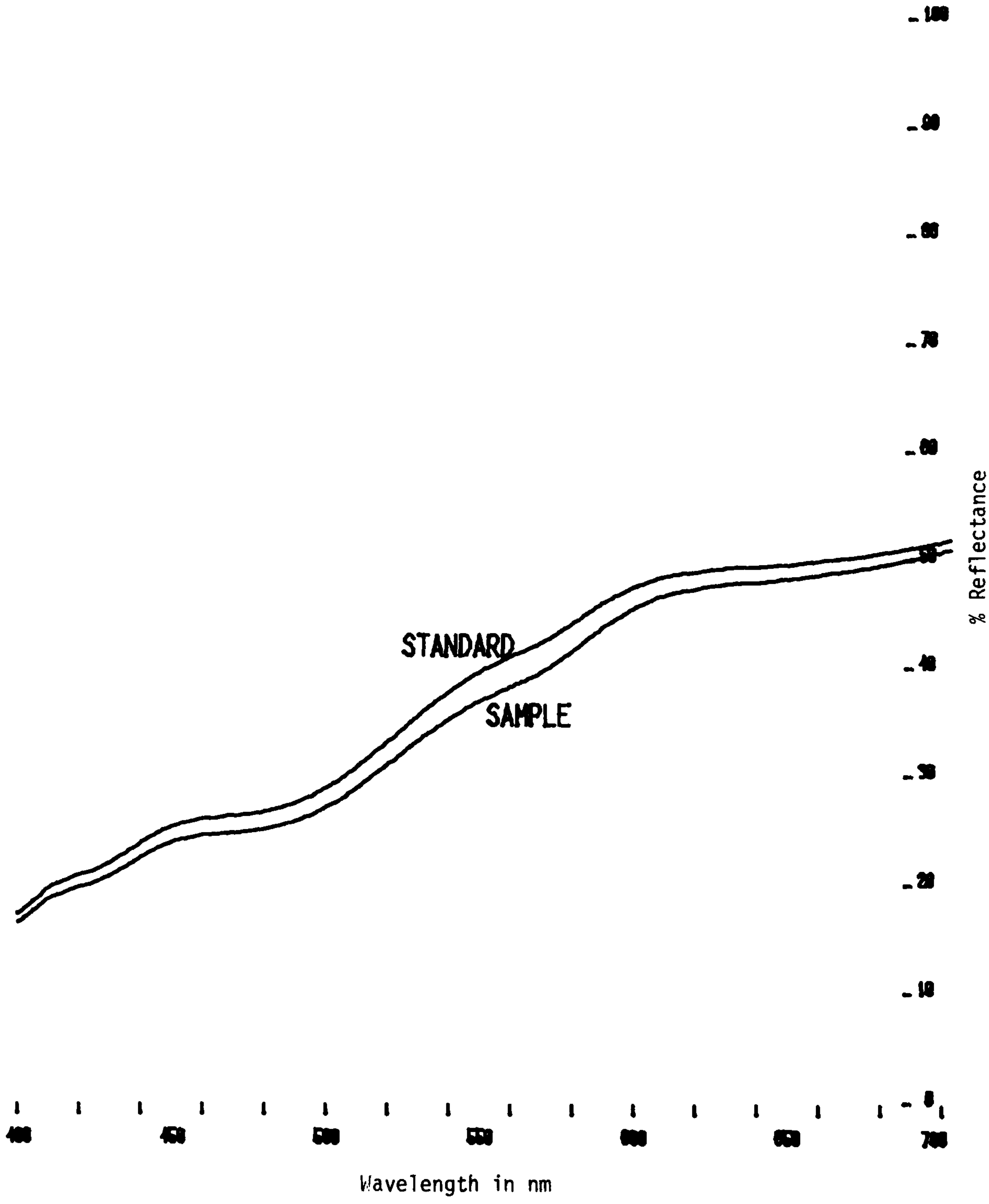

Figure 10. Reflectance curves of a pair of tan specimens with the Hunter D54.

.R QMSTAT
DATE: 10/11/80
BEGIN WITH SAMPLE NO.?(2-5)   2

MEASURE: WHITE TILES   INSERT SAMPLE THEN HIT RETURN

PAUSE --

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	99.56	99.56	99.60	0.046
410	99.64	99.66	99.62	0.037
420	99.70	99.67	99.63	0.039
430	99.69	99.66	99.62	0.044
440	99.66	99.66	99.63	0.029
450	99.61	99.61	99.62	0.024
460	99.67	99.65	99.63	0.030
470	99.66	99.63	99.62	0.027
480	99.59	99.61	99.64	0.032
490	99.63	99.62	99.63	0.013
500	99.63	99.61	99.60	0.013
510	99.59	99.58	99.59	0.018
520	99.59	99.58	99.59	0.014
530	99.61	99.59	99.60	0.019
540	99.57	99.59	99.60	0.020
550	99.62	99.61	99.59	0.022
560	99.59	99.60	99.57	0.023
570	99.57	99.57	99.59	0.013
580	99.61	99.61	99.59	0.024
590	99.58	99.59	99.60	0.021
600	99.59	99.60	99.60	0.020
610	99.63	99.63	99.62	0.023
620	99.58	99.60	99.61	0.023
630	99.62	99.61	99.62	0.025
640	99.57	99.58	99.63	0.028
650	99.66	99.67	99.66	0.021
660	99.65	99.66	99.66	0.020
670	99.70	99.70	99.68	0.030
680	99.74	99.72	99.71	0.041
690	99.63	99.68	99.69	0.041
700	99.74	99.72	99.72	0.048
710	99.79	99.80	99.77	0.049

Figure 11. Statistical study for Match-Scan.

MEASURE: AMBER FILTER   INSERT SAMPLE THEN HIT RETURN

PAUSE --

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	3.99	3.98	3.98	0.009
410	3.53	3.54	3.53	0.007
420	3.52	3.53	3.52	0.007
430	3.94	3.94	3.95	0.005
440	4.88	4.88	4.88	0.005
450	6.44	6.44	6.44	0.006
460	8.73	8.74	8.74	0.005
470	11.84	11.85	11.86	0.007
480	15.92	15.91	15.90	0.009
490	21.01	21.01	21.01	0.008
500	26.81	26.81	26.81	0.010
510	32.80	32.81	32.82	0.010
520	39.17	39.18	39.20	0.012
530	45.61	45.63	45.62	0.011
540	51.84	51.83	51.82	0.007
550	57.48	57.49	57.51	0.013
560	62.54	62.53	62.55	0.014
570	66.88	66.86	66.84	0.022
580	70.43	70.43	70.43	0.015
590	73.27	73.27	73.28	0.024
600	75.52	75.51	75.49	0.017
610	77.14	77.13	77.11	0.019
620	78.28	78.27	78.28	0.015
630	79.06	79.07	79.08	0.027
640	79.65	79.63	79.59	0.017
650	79.84	79.84	79.85	0.016
660	79.94	79.96	79.97	0.016
670	79.94	79.95	79.93	0.025
680	79.69	79.71	79.73	0.029
690	79.50	79.47	79.47	0.034
700	79.11	79.08	79.07	0.031
710	78.49	78.53	78.54	0.028

Figure 11. Statistical study for Match-Scan (continued).

MEASURE: GRAY PORCELAIN   INSERT SAMPLE THEN HIT RETURN

PAUSE --

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	42.05	42.07	42.07	0.028
410	44.43	44.39	44.40	0.024
420	44.42	44.45	44.46	0.016
430	44.23	44.24	44.24	0.020
440	44.07	44.08	44.10	0.012
450	44.02	44.03	44.03	0.019
460	43.98	44.00	44.00	0.011
470	43.97	43.97	43.98	0.013
480	44.00	43.98	43.97	0.012
490	43.96	43.98	43.97	0.010
500	43.92	43.93	43.95	0.010
510	43.95	43.94	43.94	0.009
520	43.95	43.97	43.97	0.016
530	43.95	43.95	43.95	0.011
540	43.91	43.90	43.89	0.012
550	43.81	43.80	43.80	0.016
560	43.63	43.63	43.65	0.010
570	43.49	43.49	43.48	0.009
580	43.35	43.35	43.35	0.011
590	43.27	43.26	43.26	0.013
600	43.23	43.23	43.22	0.010
610	43.25	43.25	43.25	0.011
620	43.35	43.35	43.34	0.015
630	43.39	43.42	43.40	0.017
640	43.48	43.47	43.46	0.011
650	43.47	43.48	43.49	0.017
660	43.54	43.52	43.52	0.014
670	43.55	43.53	43.55	0.016
680	43.61	43.62	43.64	0.015
690	43.80	43.78	43.77	0.008
700	43.83	43.87	43.86	0.020
710	44.06	44.05	44.02	0.025

Figure 11. Statistical study for Match-Scan (continued).

```
MEASURE: STD TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN
PAUSE --


MEASURE: SPL TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN
PAUSE --


  STD  ONE  X= 0.4249 Y= 0.4023 Z= 0.2605
  STD  AV2  X= 0.4249 Y= 0.4023 Z= 0.2605
  STD  AV10 X= 0.4248 Y= 0.4022 Z= 0.2605
  STD  SIG  X=0.00003 Y=0.00002 Z=0.00003
  SPL  ONE  X= 0.4050 Y= 0.3801 Z= 0.2459
  SPL  AV2  X= 0.4050 Y= 0.3800 Z= 0.2459
  SPL  AV10 X= 0.4048 Y= 0.3799 Z= 0.2459
  SPL  SIG  X=0.00010 Y=0.00010 Z=0.00007
  STD  ONE  L*=  69.63 A*=   6.80 B*=  19.91
  STD  AV2  L*=  69.63 A*=   6.79 B*=  19.91
  STD  AV10 L*=  69.63 A*=   6.79 B*=  19.91
  STD  SIG  L*=  0.002 A*=  0.006 B*=  0.004
  SPL  ONE  L*=  68.03 A*=   7.76 B*=  19.57
  SPL  AV2  L*=  68.02 A*=   7.76 B*=  19.57
  SPL  AV10 L*=  68.01 A*=   7.75 B*=  19.56
  SPL  SIG  L*=  0.007 A*=  0.004 B*=  0.008
ONE  DL=   1.61 DC=   0.94 DE=   1.86
AV2  DL=   1.61 DC=   0.95 DE=   1.87
AV10 DL=   1.62 DC=   0.94 DE=   1.87
SIG  DL=  0.006 DC=  0.013 DE=  0.014
STOP --
```

Figure 11. Statistical study for Match-Scan (continued).

```
?$Q"STA1
  DATE: 10/14/80
  BEGIN WITH SAMPLE NO.?(1-5)
?1

  1. ON HUNTER PRESS "TRANS",PUT WHITE TILE OVER PORT,
     BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON  HUNTER,
  4. PRESS "ASCII", THEN "2"
  5. PRESS RETURN ON SPC-16 CONSOLE
 PAUSE
?

 MEASURE: AMBER FILTER     INSERT SAMPLE,PRESS READ ON HUNTER,THEN 1ONM
 PAUSE
```

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	3.99	3.97	3.96	0.019
410	3.50	3.51	3.51	0.010
420	3.50	3.50	3.50	0.005
430	3.90	3.90	3.89	0.010
440	4.82	4.82	4.82	0.004
450	6.39	6.39	6.39	0.004
460	8.57	8.57	8.57	0.005
470	11.48	11.48	11.48	0.006
480	15.46	15.45	15.46	0.008
490	20.46	20.46	20.45	0.010
500	26.02	26.02	26.02	0.006
510	32.18	32.16	32.16	0.014
520	38.72	38.72	38.70	0.013
530	45.02	45.02	45.03	0.013
540	51.16	51.16	51.15	0.013
550	56.92	56.92	56.90	0.014
560	61.95	61.96	61.95	0.014
570	66.33	66.33	66.33	0.015
580	70.14	70.14	70.12	0.015
590	72.79	72.79	72.78	0.015
600	75.20	75.20	75.19	0.015
610	77.19	77.19	77.19	0.014
620	78.24	78.25	78.24	0.017
630	79.00	79.01	78.99	0.029
640	79.64	79.64	79.65	0.017
650	80.13	80.14	80.12	0.019
660	80.15	80.16	80.15	0.016
670	79.94	79.94	79.95	0.011
680	79.96	79.96	79.97	0.014
690	79.96	79.96	79.93	0.016
700	79.52	79.52	79.50	0.019
710	79.04	79.06	79.06	0.023

Figure 12. Statistical study for Hunter D54.

*** REMOVE AMBER FILTER***

1. ON HUNTER, PRESS "R-SIN", PUT ZERO TRAP OVER PORT
2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
3. PRESS "STDZ PUT GRAY PORCELAIN OVER PORT.
4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON HUNTER,
5. PRESS RETURN ON SPC-16 CONSOLE

PAUSE

MEASURE: WHITE TILE INSERT SAMPLE,PRESS READ ON HUNTER,THEN ION

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	95.64	95.63	95.57	0.050
410	94.66	94.65	94.63	0.023
420	94.95	94.94	94.95	0.012
430	95.71	95.70	95.71	0.011
440	96.32	96.32	96.33	0.012
450	96.95	96.94	96.95	0.014
460	97.42	97.42	97.41	0.019
470	97.71	97.71	97.69	0.018
480	97.93	97.92	97.92	0.012
490	98.12	98.12	98.12	0.012
500	98.21	98.20	98.22	0.019
510	98.20	98.21	98.22	0.013
520	98.26	98.26	98.26	0.006
530	98.49	98.49	98.51	0.019
540	98.33	98.33	98.35	0.020
550	98.35	98.35	98.36	0.010
560	98.26	98.24	98.24	0.019
570	98.34	98.33	98.34	0.011
580	98.27	98.26	98.27	0.011
590	98.45	98.45	98.46	0.013
600	98.16	98.14	98.14	0.014
610	98.14	98.14	98.15	0.019
620	98.08	98.06	98.06	0.013
630	98.16	98.14	98.14	0.016
640	98.18	98.17	98.18	0.009
650	98.15	98.14	98.17	0.018
660	98.09	98.08	98.10	0.015
670	98.19	98.19	98.20	0.011
680	97.97	97.97	97.97	0.007
690	98.21	98.21	98.20	0.007
700	98.11	98.10	98.10	0.014
710	97.94	97.94	97.98	0.028

Figure 12. Statistical study for Hunter D54 (continued).

MEASURE: GRAY PORCELAIN   INSERT SAMPLE,PRESS READ ON HUNTER,THEN [illegible]
PAUSE

W/L	FIRST	AVG OF 2	AVG OF 10	SIGMA
400	39.25	39.25	39.25	0.042
410	41.76	41.75	41.77	0.019
420	42.20	42.19	42.21	0.018
430	42.19	42.19	42.19	0.007
440	42.31	42.31	42.32	0.007
450	42.47	42.47	42.48	0.014
460	42.70	42.70	42.72	0.013
470	42.68	42.68	42.69	0.012
480	42.76	42.76	42.76	0.005
490	42.84	42.84	42.84	0.008
500	42.87	42.86	42.85	0.011
510	42.87	42.87	42.87	0.011
520	43.01	43.01	43.01	0.008
530	43.04	43.03	43.03	0.011
540	42.92	42.92	42.93	0.017
550	42.85	42.85	42.86	0.019
560	42.68	42.68	42.68	0.006
570	42.42	42.42	42.43	0.014
580	42.28	42.28	42.29	0.010
590	42.28	42.28	42.29	0.010
600	42.14	42.14	42.14	0.006
610	42.14	42.14	42.13	0.013
620	42.10	42.10	42.11	0.011
630	42.25	42.25	42.26	0.013
640	42.23	42.23	42.23	0.013
650	42.33	42.33	42.34	0.009
660	42.39	42.39	42.40	0.011
670	42.37	42.37	42.37	0.007
680	42.53	42.53	42.55	0.009
690	42.65	42.65	42.66	0.012
700	42.80	42.80	42.79	0.010
710	42.86	42.86	42.87	0.015

Figure 12. Statistical study on Hunter D54 (continued).

```
MEASURE: STD TAN PLASTIC  INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10NM
PAUSE
MEASURE: SPL TAN PLASTIC  INSERT SAMPLE,PRESS READ ON HUNTER,THEN 10NM
PAUSE
  STD   ONE  X= 0.4127 Y= 0.3911 Z= 0.2500
  STD   AV2  X= 0.4127 Y= 0.3911 Z= 0.2500
  STD   AV10 X= 0.4127 Y= 0.3911 Z= 0.2500
  STD   SIG  X=0.00003 Y=0.00002 Z=0.00003
  SPL   ONE  X= 0.3927 Y= 0.3689 Z= 0.2358
  SPL   AV2  X= 0.3928 Y= 0.3690 Z= 0.2358
  SPL   AV10 X= 0.3929 Y= 0.3691 Z= 0.2358
  SPL   SIG  X=0.00007 Y=0.00008 Z=0.00005
  STD   ONE  L*=  68.83 a*=    6.60 b*=  20.27
  STD   AV2  L*=  68.83 a*=    6.61 b*=  20.27
  STD   AV10 L*=  68.83 a*=    6.60 b*=  20.28
  STD   SIG  L*=  0.001 a*=   0.007 b*=  0.005
  SPL   ONE  L*=  67.20 a*=    7.54 b*=  19.89
  SPL   AV2  L*=  67.20 a*=    7.54 b*=  19.89
  SPL   AV10 L*=  67.21 a*=    7.54 b*=  19.90
  SPL   SIG  L*=  0.006 a*=   0.00[illegible] b*=  0.005
ONE   DL=    1.63 DC=    0.89 DE=    1.86
AV2   DL=    1.63 DC=    0.89 DE=    1.85
AV10  DL=    1.62 DC=    0.90 DE=    1.85
SIG   DL=   0.006 DC=   0.022 DE=   0.023
STOP
```

Figure 12. Statistical study of Hunter D54 (continued).

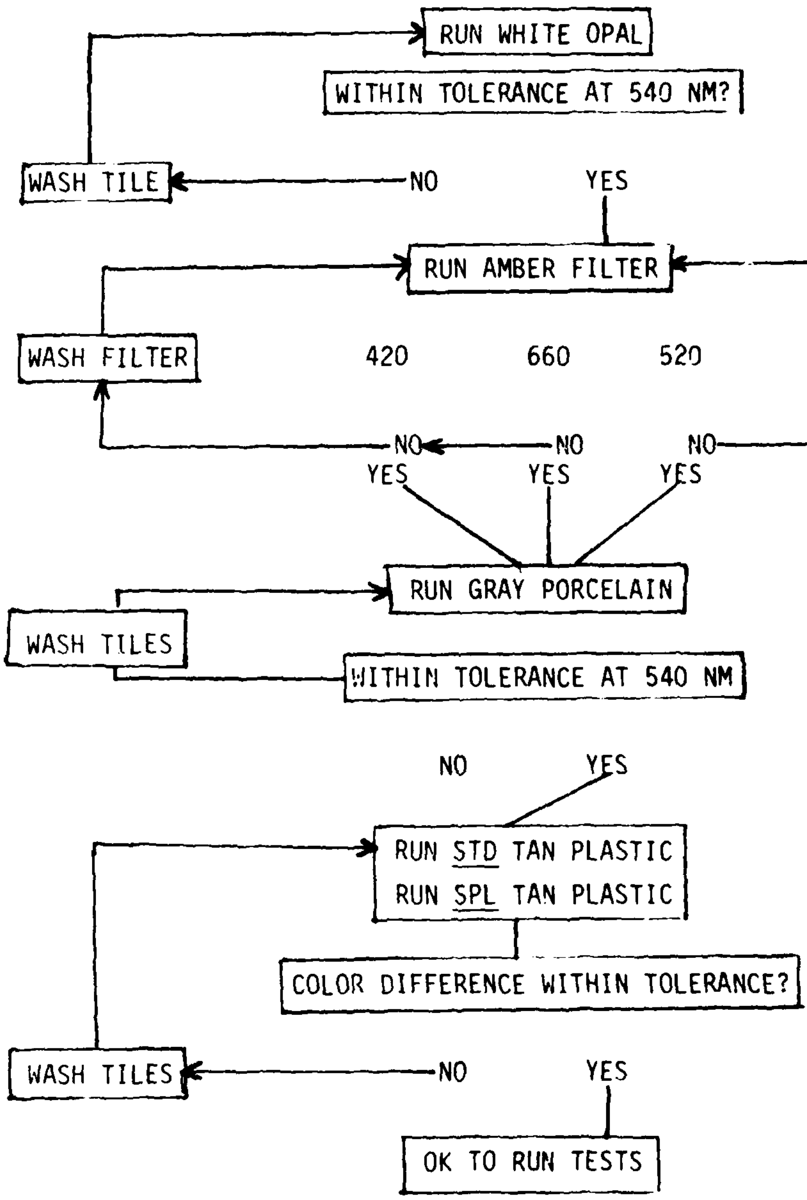

Figure 13. Schematic of standardization of Match-Scan.

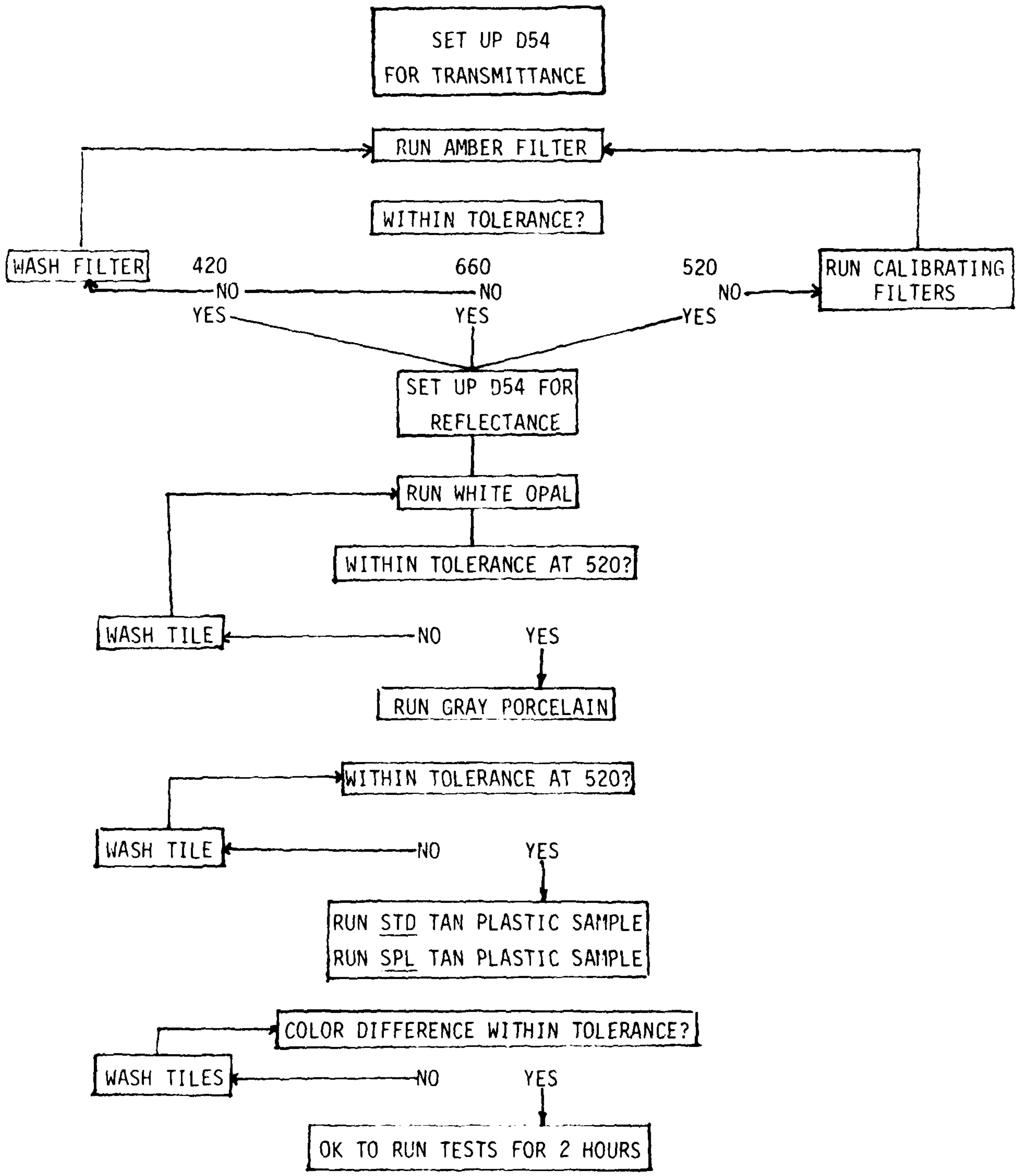

Figure 14. Schematic of standardization of Hunter D54.

```
DATE:  1/25/81
 BEGIN WITH SAMPLE NO.?(1-5)        1

MEASURE: WHITE TILES        INSERT SAMPLE THEN HI~ RETURN AFTER PAUSE
AT 540 NM UPPEv LIMIT  99.62 LOWER LIMIT  99.48
PAUSE --


W/L      FIRST    AVG OF 2
 540      99.54     99.53

MEASURE: AMBER FILTER       INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
AT 420 NM UPPER LIMIT   3.53 LOWER LIMIT   3.47
AT 520 NM UPPER LIMIT  39.27 LOWER LIMIT  38.93
AT 660 NM UPPER LIMIT  80.09 LOWER LIMIT  79.85
PAUSE --


W/L      FIRST    AVG OF 2
 420       3.49      3.49
 520      39.15     39.16
 660      80.00     79.96

MEASURE: GRAY PORCELAIN   INSERT SAMPLE THEN HIT RE~URN AFTER PAUSE
AT 540 NM UPPER LIMIT  44.00 LOWER LIMIT  43.80
PAUSE --


W/L      FIRST    AVG OF 2
 540      43.92     43.94

MEASURE: STD TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
COLOR DIFF. UPPER LIMIT   1.94 LOWER LIMIT   1.84
PAUSE --


MEASURE: SPL TAN PLASTIC  INSERT SAMPLE THEN HIT RETURN AFTER PAUSE
PAUSE --


AVG OF 2  DL=   1.60 DC=   0.97 DE=   1.87
STOP --
```

Figure 15. Standardization test for Match-Scan, typical output from QMSTAN computer program.

```
?$OSTANH
 DATE:  1/27/81
 BEGIN WITH SAMPLE NO.? (1-5)
?1

  1. ON D54 PRESS "ASCII OUT", THEN "O", THEN "TRANS"
       PUT WHITE PORCELAIN OVER PORT,
       BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54
  4. PRESS "ASCII", THEN "2",
  5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: AMBER FILTER       INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L      FIRST     AVG OF 2
   420       3.49       3.49
   520      38.76      38.74
   660      80.20      80.20
 *** REMOVE AMBER FILTER***
  1. ON D54, PRESS "ASCII",THEN "O",THEN "R-SIN"/       PUT ZERO TRAP
  2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
  3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT
  4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54,
  5. PRESS "ASCII", THEN "2"
  6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: WHITE TILE        INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
  AT 540 NM UPPER LIMIT 98.46 LOWER LIMIT 98.26
 PAUSE
?
 PAUSE
?
  W/L      FIRST     AVG OF 2
   540      98.40      98.40
```

Figure 16. Standardization test for Hunter D54, typical output from QSTANH computer program.

```
MEASURE: GRAY PORCELAIN   INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
 AT 540 NM UPPER LIMIT 43.06 LOWER LIMIT 42.86
PAUSE
?
PAUSE
?
 W/L      FIRST    AVG OF 2
  540     42.92     42.92
 MEASURE: STD TAN PLASTIC  INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
 COLOR DIFFERENCE: UPPER LIMIT  1.93 LOWER LIMIT  1.83
PAUSE
?
PAUSE
?

 MEASURE: SPL TAN PLASTIC  INSERT SAMPLE IN D54:
   AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
   AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME
PAUSE
?
PAUSE
?

ONE  DL=   1.63 DC=   0.88 DE=   1.85.

AV2  DL=   1.62 DC=   0.87 DE=   1.84

***OK TO MAKE MEASUREMENTS***
STOP
```

Figure 16. Standardization test for Hunter D54 (continued).

```
?$0STAHH
  DATE:  1/27/81
  BEGIN WITH SAMPLE NO.? (1-5)
?1

  1. ON D54 PRESS "ASCII OUT", THEN "O", THEN "TRANS"
        PUT WHITE PORCELAIN OVER PORT.
        BLOCK BEAM WITH BLACK CARDBOARD
  2. PRESS "ZERO". REMOVE CARDBOARD
  3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54
  4. PRESS "ASCII", THEN "2".
  5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
?

  MEASURE: AMBER FILTER      INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "IONM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L      FIRST    AVG OF 2
   420       3.76      3.77
 ***READING AT  420NM IS OUT OF SPECS FOR:AMBER FILTER
     WASH SAMPLE, THEN

  MEASURE: AMBER FILTER      INSERT SAMPLE IN D54:
    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54
    AFTER BELL RINGS, PRESS "IONM" AND "RETURN" AT SAME TIME
  AT 420 NM UPPER LIMIT  3.51 LOWER LIMIT  3.45
  AT 520 NM UPPER LIMIT 38.86 LOWER LIMIT 38.50
  AT 660 NM UPPER LIMIT 80.32 LOWER LIMIT 80.08
 PAUSE
?
 PAUSE
?
  W/L      FIRST    AVG OF 2
   420       3.48      3.48
   520      38.74     38.74
   660      80.14     80.15

 *** REMOVE AMBER FILTER***
  1. ON D54, PRESS "ASCII",THEN "O",THEN "R-SIN"/       PUT ZERO TRAP
  2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT
  3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT
  4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54.
  5. PRESS "ASCII", THEN "2"
  6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER
 PAUSE
```

Figure 16. Standardization tests for Hunter D54 (continued).

APPENDICES

Appendix A

Computer Program QMSTST for Match-Scan Statistical Study.

```
      PROGRAM QMSTAT
C       --- TO CALCULATE STATISTICAL DATA FOR A STANDARDIZATION
C       PROCEDURE APPLICABLE TO THE MATCH-SCAN
C
C       LINK INSTRUCTIONS:
C       ASS DX1 DK
C       R LINK
C       *QMSTAT=QMSTAT,DXO:MSLIB,FISNOV.NEW
C
C
        DIMENSION AVGNO(4),CMF(3,32),D65(32),FAC(32,3),FACT(32),PLAS
        DIMENSION R(32,10),RC(32,13,2),RG(32),STAR(3,13,2),SPL(4,5)
        DIMENSION TRI(3,13,2),TRIO(3),VAL(3),DSQ(3),AVG(3),CD(3,13)
       DATA CMF/0.0191,0.0020,0.0860
     X,  0.0847,0.0088,0.3894
     X,  0.2045,0.0214,0.9725
     X,  0.3147,0.0387,1.5535
     X,  0.3837,0.0621,1.9673
     X,  0.3707,0.0895,1.9948
     X,  0.3023,0.1282,1.7454
     X,  0.1956,0.1852,1.3176
     X,  0.0805,0.2536,0.7721
     X,  0.0162,0.3391,0.4153
     X,  0.0038,0.4608,0.2185
     X,  0.0375,0.6067,0.1120
     X,  0.1177,0.7618,0.0607
     X,  0.2365,0.8752,0.0305
     X,  0.3768,0.9620,0.0137
     X,  0.5298,0.9918,0.0040
     X,  0.7052,0.9973,0.0000
     X,  0.8787,0.9556,0.0000
     X,  1.0142,0.8689,0.0000
     X,  1.1185,0.7774,0.0000
     X,  1.1240,0.6583,0.0000
     X,  1.0305,0.5280,0.0000
     X,  0.8563,0.3981,0.0000
     X,  0.6475,0.2835,0.0000
     X,  0.4316,0.1798,0.0000
     X,  0.2683,0.1076,0.0000
     X,  0.1526,0.0603,0.0000
     X,  0.0813,0.0318,0.0000
     X,  0.0409,0.0159,0.0000
     X,  0.0199,0.0077,0.0000
     X,  0.0096,0.0037,0.0000
     X,  0.0046,0.0018,0.0000/
        DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,108
     X,  1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.
     X,  900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./

        DATA SPL/'WHIT','E TI','LES ','    ','AMBE','R FI','LTER','
     X  'GRAY',' POR','CELA','IN  ','STD ','TAN ','PLAS','TIC ','SPL ',
     X  'TAN ','PLAS','TIC '/
        DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG','STD ','SPL '/
100     FORMAT(' DATE: 'I2,2('/',I2))
150     FORMAT('$ BEGIN WITH SAMPLE NO.?(2-5)',63)
```

```
200     FORMAT('OMEASURE: '4A4,' INSERT SAMPLE THEN HIT RETURN'/)
300     FORMAT(I5,3F10.2,F10.3)
400     FORMAT(1H0,2(2X,A4),' X=',F7.4,' Y=',F7.4,' Z=',F7.4)
450     FORMAT(1H0,2(2X,A4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500     FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2',2X,'AVG OF 10',4X,'SIGM
600     FORMAT(1H0,2(2X,A4),' L*=',F7.2,' A*=',F7.2,' B*=',F7.2)
650     FORMAT(1H0,2(2X,A4),' L*=',F7.3,' A*=',F7.3,' B*=',F7.3)
700     FORMAT(1H0,A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
750     FORMAT(1H0,A4,' DL=',F7.3,' DC=',F7.3,' DE=',F7.3)
        CALL IDATE(IM,ID,IY)
        WRITE(5,100) IM,ID,IY
        WRITE(5,150)
        READ(5,300) NSAM
        DO 2000 II=1,5
        IF(II.EQ.1) GOTO 960
        IF(II.LT.NSAM) GOTO 2000
960     I=II
        WRITE(5,200) (SPL(M,I),M=1,4)
        PAUSE
        DO 1000 N=1,10
        DO 980 L=1,32
980     FACT(L)=1.
        CALL GMSR(4000,7100,100,1,0,5,0,1,FACT,RG,IER)
        DO 990 L=1,32
990     R(L,N)=RG(L)
        CALL IDLE(1000)
1000    CONTINUE
        IF(I.LT.4) WRITE(5,500)
        IF(I.GT.1) GOTO 1100
        DO 1040 L=1,32
        FAC(L,2)=0.
        FAC(L,3)=0.
        DELSQ=0.
        DO 1020 N=1,10
        IF(N.EQ.1) FAC(L,1)=R(L,N)
        IF(N.LE.2) FAC(L,2)=R(L,N)*0.5 + FAC(L,2)
        FAC(L,3)=R(L,N)*0.1 + FAC(L,3)
1020    CONTINUE
        DO 1030 N=1,10
1030    DELSQ=(R(L,N)-FAC(L,3))*(R(L,N)-FAC(L,3)) - DELSQ
        SIGMA=SQRT(DELSQ*0.1111)
        WRITE(5,300) 390+L*10,(FAC(L,M),M=1,3),SIGMA
        DO 1035 M=1,3
1035    FAC(L,M)=FAC(L,M)*0.01
1040    CONTINUE
        GOTO 2000
1100    DO 1140 L=1,32
        VAL(2)=0.
        VAL(3)=0.
        DELSQ=0.
        DO 1120 N=1,10
        IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
        IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
        IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
```

```
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
      R(L,N)=R(L,N)/FAC(L,3)
      VAL(3)=R(L,N)*0.1 + VAL(3)
      IF(I.GE.4) RC(L,3,I-3)=VAL(3)
      IF(I.GE.4) RC(L,3+N,I-3)=R(L,N)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      DO 1130 N=1,10
1130  DELSQ=(R(L,N)-VAL(3))*(R(L,N)-VAL(3)) + DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      WRITE(5,300) 390+L*10,(VAL(M),M=1,3),SIGMA
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      J1=1
      J3=3
      DO 2970 I=1,3
2970  AVG(I)=0.
2980  DO 3050 J=J1,J3
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K) + RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
      IF(J1.GT.3) GOTO 3030
      WRITE(5,400) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
      GOTO 3050
3030  DO 3040 I=1,3
      AVG(I)=AVG(I) + TRI(I,J,K)*0.1
3040  CONTINUE
3050  CONTINUE
      IF(J1.EQ.4) GOTO 3060
      J1=4
      J3=13
      GOTO 2980
3060  DO 3068 I=1,3
      DSQ(I)=0.
      DO 3065 J=4,13
3065  DSQ(I)=(TRI(I,J,K)-AVG(I))*(TRI(I,J,K)-AVG(I)) + DSQ(I)
      DSQ(I)=SQRT(DSQ(I)*0.1111)
3068  CONTINUE
      WRITE(5,450) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,13
      DO 3080 K=1,2
```

```
3080    TRI(I,J,K)=TRI(I,J,K)**TH
        DO 3170 K=1,2
        J1=1
        J3=3
        DO 3100 I=1,3
3100    AVG(I)=0.
3110    DO 3150 J=J1,J3
        STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
        STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
        STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
        IF(J1.GT.3) GOTO 3130
        WRITE(5,600) PLAST(K),AVGNO(J),(STAR(M,J,K),M=1,3)
        GOTO 3150
3130    DO 3140 I=1,3
3140    AVG(I)=AVG(I)+STAR(I,J,K)*0.1
3150    CONTINUE
        IF(J1.EQ.4) GOTO 3160
        J1=4
        J3=13
        GOTO 3110
3160    DO 3168 I=1,3
        DSQ(I)=0.
        DO 3165 J=4,13
3165    DSQ(I)=(STAR(I,J,K)-AVG(I))*(STAR(I,J,K)-AVG(I)) +DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3168    CONTINUE
        WRITE(5,650) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3170    CONTINUE
        J1=1
        J3=3
        DO 3175 I=1,3
3175    AVG(I)=0.
3180    DO 3250 J=J1,J3
        DO 3200 I=1,3
3200    STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
        CD(1,J)=SQRT(STAR(1,J,1))
        CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1) + STAR(3,J,1)*STAR(3,J,1))
        CD(3,J)=SQRT(CD(1,J)*CD(1,J) + CD(2,J)*CD(2,J))
        IF(J1.GT.3) GOTO 3230
        WRITE(5,700) AVGNO(J),(CD(M,J),M=1,3)
        GOTO 3250
3230    DO 3240 I=1,3
3240    AVG(I)=AVG(I) + CD(I,J)*0.1
3250    CONTINUE
        IF(J1.NE.1) GOTO 3260
        J1=4
        J3=13
        GOTO 3180
3260    DO 3268 I=1,3
        DSQ(I)=0.
        DO 3265 J=4,13
3265    DSQ(I)=(CD(I,J)-AVG(I))*(CD(I,J)-AVG(I)) + DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3268    CONTINUE
        WRITE(5,750) AVGNO(4),(DSQ(M),M=1,3)
4000    STOP
        END
```

Appendix B.

Computer program QMSTAT for Hunter D54 statistical study.

```
?$COPY,DS(QMSTAT),TY
C       PROGRAM QMSTAT
C       ---TO CALCULATE STATISTICAL DATA FOR A STANDARDIZED PROCEDURE
C       APPLICABLE TO THE HUNTER D54P SPECTROPHOTOMETER
        DIMENSION AVGNO(4),CMF(3,32),D65(32),FAC(32,3),PLAST(2)
        DIMENSION R(32,10),RC(32,13,2),RG(32),STAR(3,13,2),SPL(4,5)
        DIMENSION TRI(3,13,2),TRIO(3),VAL(3),DSQ(3),AVG(3),CD(3,13)
        DIMENSION NWL(32)
        DATA CMF/0.0191,0.0020,0.0860,0.0847,0.0088,0.3894
     -,0.2045,0.0214,0.9725,0.3147,0.0387,1.5535
     -,0.3837,0.0621,1.9673,0.3707,0.0895,1.9948
     -,0.3023,0.1282,1.7454,0.1956,0.1852,1.3176
     -,0.0805,0.2536,0.7721,0.0162,0.3391,0.4153
     -,0.0038,0.4608,0.2185,0.0375,0.6067,0.1120
     -,0.1177,0.7618,0.0607,0.2365,0.8752,0.0305
     -,0.3768,0.9620,0.0137,0.5298,0.9918,0.0040
     -,0.7052,0.9973,0.0000,0.8787,0.9556,0.0000
     -,1.0142,0.8689,0.0000,1.1185,0.7774,0.0000
     -,1.1240,0.6583,0.0000,1.0305,0.5280,0.0000
     -,0.8563,0.3981,0.0000,0.6475,0.2835,0.0000
     -,0.4316,0.1798,0.0000,0.2683,0.1076,0.0000
     -,0.1526,0.0603,0.0000,0.0813,0.0318,0.0000
     -,0.0409,0.0159,0.0000,0.0199,0.0077,0.0000
     -,0.0096,0.0037,0.0000,0.0046,0.0018,0.0000/
        DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.,
     -1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.,
     -900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
        DATA SPL/'WHIT','E TI','LES ','    ','AMBE','R FI','LTER','    ',
     -'GRAY',' POR','CELA','IN  ','STD ','TAN ','PLAS','TIC','SPL ',
     -'TAN ','PLAS','TIC '/
        DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG','STD ','SPL '/
100     FORMAT(' DATE: ',I2,2('/',I2))
150     FORMAT(' BEGIN WITH SAMPLE NO.?(1-5)',6X)
200     FORMAT(// MEASURE: '4A4,' INSERT SAMPLE,PRESS READ ON HUNTER,THEN
     - 10NM')
300     FORMAT(I5,3F10.2,F10.3)
350     FORMAT(I3,F11.2)
400     FORMAT(/2(2XA4),' X=',F7.4,' Y=',F7.4,' Z=',F7.4)
450     FORMAT(/2(2XA4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500     FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2',2X,'AVG OF 10',4X,'SIGMA')
600     FORMAT(/2(2XA4),' L*=',F7.2,' a*=',F7.2,' b*=',F7.2)
650     FORMAT(/2(2XA4),' L*=',F7.3,' a*-',F7.3,' b*=',F7.3)
700     FORMAT(/A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
750     FORMAT(/A4,' DL=',F7.3,' DC=',F7.3,' DE=',F7.3)
        CALL DATE$B(IY,IM,ID)
        WRITE(5,100) IM,ID,IY
        WRITE(5,150)
        READ(5,350) NSAM
        IF(NSAM.GT.1) GOTO 950
        WRITE(5,150)
950     DO 2000 II=1,5
```

```
      IF(II.LT.NSAM) GOTO 2000
960   I=II
      WRITE(5,200) (SPL(M,I),M=1,4)
      DO 1000 N=1,10
      PAUSE
      DO  980 L=1,32
      READ(14,350) NWL(L),RG(L)
980   CONTINUE
      DO 935 L=1,32
      R(L,N)=RG(L)
935   CONTINUE
1000  CONTINUE
      IF (I.LT.4) WRITE(5,500)
      IF(I.GT.1) GOTO 1100
      DO 1040 L=1,32
      FAC(L,2)=0
      FAC(L,3)=0
      DELSQ=0.
      DO 1020 N=1,10
      IF(N.EQ.1) FAC(L,1)=R(L,N)
      IF(N.LE.2) FAC(L,2)=R(L,N)*0.5+ FAC(L,2)
      FAC(L,3)=R(L,N)*0.1 + FAC(L,3)
1020  CONTINUE
      DO 1030 N=1,10
1030  DELSQ=(R(L,N)-FAC(L,3))*(R(L,N)-FAC(L,3)) +DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      NM=390+L*10
      WRITE(5,300) NM,(FAC(L,M),M=1,3),SIGMA
      DO 1035 M=1,3
1035  FAC(L,M)=FAC(L,M)*0.01
1040  CONTINUE
      GOTO 2000
1100  DO 1140 L=1,32
      VAL(2)=0.
      VAL(3)=0.
      DELSQ=0.
      DO 1120 N=1,10
      IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
      IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
      IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
      R(L,N)=R(L,N)/FAC(L,3)
      VAL(3)=R(L,N)*0.1+VAL(3)
      IF(I.GE.4) RC(L,3,I-3)=VAL(3)
      IF(I.GE.4) RC(L,3+N,I-3)=R(L,N)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      DO 1130 N=1,10
1130  DELSQ=(R(L,N)-VAL(3))*(R(L,N)-VAL(3))+DELSQ
      SIGMA=SQRT(DELSQ*0.1111)
      NM=390+L*10
```

```
      WRITE(5,300)NM,(VAL(M),M=1,3),SIGMA
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      J1=1
      J3=3
      DO 2970 I=1,3
2970  AVG(I)=0.
2980  DO 3050 J=J1,J3
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K)+RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
      IF(J1.GT.3) GOTO 3030
      WRITE(5,400) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
      GOTO 3050
3030  DO 3040 I=1,3
      AVG(I)=AVG(I)+TRI(I,J,K)*0.1
3040  CONTINUE
3050  CONTINUE
      IF(J1.EQ.4) GOTO 3060
      J1=4
      J3=13
      GOTO 2980
3060  DO 3068 I=1,3
      DSQ(I)=0.
      DO 3065 J=4,13
3065  DSQ(I)=(TRI(I,J,K)-AVG(I))*(TRI(I,J,K)-AVG(I))+DSQ(I)
      DSQ(I)=SQRT(DSQ(I)*0.1111)
3068  CONTINUE
      WRITE(5,450) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,13
      DO 3080 K=1,2
3080  TRI(I,J,K)=TRI(I,J,K)**TH
      DO 3170 K=1,2
      J1=1
      J3=3
      DO 3100 I=1,3
```

```
3100    AVG(I)=0.
3110    DO 3150 J=J1,J3
        STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
        STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
        STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
        IF(J1.GT.3) GOTO 3130
        WRITE(5,600) PLAST(K),AVGNO(J),(STAR(M,J,K),M=1,3)
        GOTO 3150
3130    DO 3140 I=1,3
3140    AVG(I)=AVG(I)+STAR(I,J,K)*0.1
3150    CONTINUE
        IF(J1.EQ.4) GOTO 3160
        J1=4
        J3=13
        GOTO 3110
3160    DO 3168 I=1,3
        DSQ(I)=0.
        DO 3165 J=4,13
3165    DSQ(I)=(STAR(I,J,K)-AVG(I))*(STAR(I,J.K)-AVG(I))+DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3168    CONTINUE
        WRITE(5,650) PLAST(K),AVGNO(4),(DSQ(I),I=1,3)
3170    CONTINUE
        J1=1
        J3=3
        DO 3175 I=1,3
3175    AVG(I)=0.
3180    DO 3250 J=J1,J3
        DO 3200 I=1,3
3200    STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
        CD(1,J)=SQRT(STAR(1,J,1))
        CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1)+STAR(3,J,1)*STAR(3,J,1))
        CD(3,J)=(CD(1,J)*CD(1,J)+CD(2,J)*CD(2,J))
        IF(J1.GT.3) GOTO 3230
        WRITE(5,700)AVGNO(J),(CD(M,J),M=1,3)
        GOTO 3250
3230    DO 3240 I=1,3
3240    AVG(I)=AVG(I)+CD(I,J)*0.1
3250    CONTINUE
        IF(J1.NE.1) GOTO 3260
        J1=4
        J3=13
        GOTO 3180
3260    DO 3268 I=1,3
        DSQ(I)=0.
        DO 3265 J=4,13
3265    DSQ(I)=(CD(I,J)-AVG(I))*(CD(I,J)-AVG(I))+DSQ(I)
        DSQ(I)=SQRT(DSQ(I)*0.1111)
3268    CONTINUE
        WRITE(5,750) AVGNO(4),(DSQ(M),M=1,3)
4000    STOP
        END
```

Appendix C

Computer Program QMSTAN for Standardization Program of Match-Scan.

```
      PROGRAM QMSTAN
C     ---TO PROVIDE A STANDARDIZATION
C     PROCEDURE APPLICABLE TO THE MATCH-SCAN
C
C     LINK INSTRUCTIONS:
C     ASS DX1 DK
C     R LINK
C     *QMSTAN=QMSTAN,DX0:MSLIB,FISNOV.NEW
C
C
      DIMENSION CMF(3,32),D65(32),FAC(32,3),FACT(32)
      DIMENSION R(32,10),RC(32,2,2),RG(32),STAR(3,2,2),SPL(4,5)
      DIMENSION UL(6),OW(6),NM(5),AC(6)
      DIMENSION TRI(3,2,2),TRIO(3),VAL(3),CD(3,2)

     DATA CMF/0.0191,0.0020,0.0860
    X,  0.0847,0.0088,0.3894
    X,  0.2045,0.0214,0.9725
    X,  0.3147,0.0387,1.5535
    X,  0.3837,0.0621,1.9673
    X,  0.3707,0.0895,1.9948
    X,  0.3023,0.1282,1.7454
    X,  0.1956,0.1852,1.3176
    X,  0.0805,0.2536,0.7721
    X,  0.0162,0.3391,0.4153
    X,  0.0038,0.4608,0.2185
    X,  0.0375,0.6067,0.1120
    X,  0.1177,0.7618,0.0607
    X,  0.2365,0.8752,0.0305
    X,  0.3768,0.9620,0.0137
    X,  0.5298,0.9918,0.0040
    X,  0.7052,0.9973,0.0000
    X,  0.8787,0.9556,0.0000
    X,  1.0142,0.8689,0.0000
    X,  1.1185,0.7774,0.0000
    X,  1.1240,0.6583,0.0000
    X,  1.0305,0.5280,0.0000
    X,  0.8563,0.3981,0.0000
    X,  0.6475,0.2835,0.0000
    X,  0.4316,0.1798,0.0000
    X,  0.2683,0.1076,0.0000
    X,  0.1526,0.0603,0.0000
    X,  0.0813,0.0318,0.0000
    X,  0.0409,0.0159,0.0000
    X,  0.0199,0.0077,0.0000
    X,  0.0096,0.0037,0.0000
    X,  0.0046,0.0018,0.0000/
      DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.
    X,  1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.
    X,  900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
      DATA SPL/'WHIT','E TI','LES ','    ','    ','AMBE','R FI','LTER','    '.
    X  'GRAY',' FOR','CELA','IN  ','STD ','TAN ','PLAS','TIC ','SPL ',
    X  'TAN ','PLAS','TIC '/
```

```
C        1=OPAL@540;2=AMBER@420;3=AMBER@520;4=AMBER@660;5=GRAY@540;6=COL DIF
         DATA NM/540,420,520,660,540/
         DATA UL/99.62,3.53,39.27,80.09,44.00,1.94/
         DATA OW/99.48,3.47,38.93,79.85,43.80,1.84/
         DATA    AC/'UPPE','R LI','MIT ','LOWE','R LI','MIT '/
100      FORMAT(' DATE: 'I2,2('/',I2))
150      FORMAT('$ BEGIN WITH SAMPLE NO.?(1-5)',6X)
160      FORMAT(' AT',I4,' NM',2(1X3A4,F6.2))
170      FORMAT(' COLOR DIFF.',2(1X3A4,F6.2))
D175     FORMAT('$   CHANGE LIMITS? 0=NO; 1=YES',4X)
180      FORMAT(2X3A4,'?')
190      FORMAT(F7.2)
200      FORMAT('OMEASURE: '4A4,
     X'  INSERT SAMPLE THEN HIT RETURN AFTER PAUSE')
210      FORMAT('O**READING AT',I5,' NM IS OUT OF SPECS FOR: ',4A4,/
     X'       WASH SAMPLE, THEN')
220      FORMAT('*** COLOR DIFFERENCE IS OUT OF SPECS'/
     X'          WASH PLASTIC TILES, THEN')
300      FORMAT(I5,3F10.2,F10.3)
500      FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2')
700      FORMAT(1HO,'AVG OF 2  DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
         CALL IDATE(IM,ID,IY)
         WRITE(5,100) IM,ID,IY
         WRITE(5,150)
         READ(5,300) NSAM
950      DO 2000 I=1,5
         IF(I.NE.1.AND.I.LT.NSAM) GOTO 2000
960      WRITE(5,200) (SPL(M,I),M=1,4)
         IF(I.EQ.5) GOTO 975
         IF(I.LE.2) K=0
         IF(I.GE.3) K=2
         IF(I.EQ.4) GOTO 970
965      WRITE(5,160) NM(I+K),(AC(M),M=1,3),UL(I+K),(AC(M),M=4,6),OW(I+K)
970      IF(I.EQ.4) WRITE(5,170) (AC(M),M=1,3),UL(6),(AC(M),M=4,6),OW(6)
D        WRITE(5,175)
D        READ(5,300) ICH
D        IF(ICH.EQ.0) GOTO 972
D        WRITE(5,180) (AC(M),M=1,3)
D        READ(5,190) UL(I+K)
D        WRITE(5,180) (AC(M),M=4,6)
D        READ(5,190) OW(I+K)
972      IF(I.NE.2) GOTO 975
         IF(K.LT.3) K=K+1
         IF(K.LT.3)GOTO 965
975      CONTINUE
         PAUSE
         DO 1000 N=1,2
         DO 980 L=1,32
980      FACT(L)=1.
         CALL GMSR(4000,7100,100,1,0,5,0,1,FACT,RG,IER)
         DO 990 L=1,32
990      R(L,N)=RG(L)
         CALL IDLE(1000)
1000     CONTINUE
```

```
          IF(I.LT.4) WRITE(5,500)
          IF(I.GT.1) GOTO 1100
          DO 1040 L=1,32
          FAC(L,2)=0.
          DO 1020 N=1,2
          IF(N.EQ.1) FAC(L,1)=R(L,N)
          IF(N.LE.2) FAC(L,2)=R(L,N)*0.5 + FAC(L,2)
1020      CONTINUE
          IF(L.NE.15) GOTO 1030
                   WRITE(5,300) 390+L*10,(FAC(L,M),M=1,2)
          IF(FAC(15,2).LT.UL(1).AND.FAC(15,2).GT.OW(1)) GOTO 1030
          WRITE(5,210) 540,(SPL(M,1),M=1,4)
          GOTO 960
1030      DO 1035 M=1,2
1035      FAC(L,M)=FAC(L,M)*0.01
1040      CONTINUE
          GOTO 2000
1100      DO 1500 L=1,32
          VAL(2)=0.
          DO 1120 N=1,2
          IF(N.EQ.1) VAL(1)=R(L,N)/FAC(L,1)
          IF(N.EQ.1.AND.I.GE.4)RC(L,1,I-3)=VAL(1)
          IF(N.LE.2) VAL(2)=R(L,N)*0.5/FAC(L,2)+VAL(2)
          IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
1120      CONTINUE
          LL=L/10+2
          IF(I-3) 1140,1160,1500
1140      IF(L.EQ.3.OR.L.EQ.13.OR.L.EQ.27) GOTO 1150
          GOTO 1500
1150      WRITE(5,300) 390+L*10, (VAL(M),M=1,2)
          IF(VAL(2).LT.UL(LL).AND.VAL(2).GT.OW(LL)) GOTO 1500
          WRITE(5,210) 390+L*10,(SPL(M,I),M=1,4)
          GOTO 960
1160      IF(L.NE.15) GOTO 1500
          WRITE(5,300) 540,(VAL(M),M=1,2)
          IF(VAL(2).LT.UL(5).AND.VAL(2).GT.OW(5)) GOTO 1500
          WRITE(5,210) 540,(SPL(M,3),M=1,4)
          GOTO 960
1500      CONTINUE
2000      CONTINUE
C         I IS THE TRISTIMULUS COUNTER
C         J IS THE AVERAGES COUNTER
C         K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C         L IS THE WAVELENGTH COUNTER
          DO 2900 I=1,3
          TRIO(I)=0.
          DO 2900 L=1,32
2900      TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
          TH=1./3.
          DO 3050 K=1,2
          DO 3050 J=1,2
          DO 3020 I=1,3
          TRI(I,J,K)=0.
          DO 3000 L=1,32
```

```
3000     TRI(I,J,K)=TRI(I,J,K) + RC(L,J,K)*CMF(I,L)*D65(L)
3020     TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
3050     CONTINUE
         DO 3080 I=1,3
         DO 3080 J=1,2
         DO 3080 K=1,2
3080     TRI(I,J,K)=TRI(I,J,K)**TH
         DO 3150 K=1,2
         DO 3150 J=1,2
         STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
         STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
3150     STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
         J=2
         DO 3200 I=1,3
3200     STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
         CD(1,J)=SQRT(STAR(1,J,1))
         CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1) + STAR(3,J,1)*STAR(3,J,1))
         CD(3,J)=SQRT(CD(1,J)*CD(1,J) + CD(2,J)*CD(2,J))
         WRITE(5,700) (CD(M,J),M=1,3)
         IF(CD(3,2).LT.UL(6).AND.CD(3,2).GT.OW(6)) GOTO4000
         WRITE(5,220)
         NSAM=4
         GOTO 950
4000     STOP
         END
```

Appendix D

Computer program QSTANH for standardization program of Hunter D54.

```
C       PROGRAM QSTANH
C       ---TO PROVIDE A STANDARDIZATION PROCEDURE
C       APPLICABLE TO THE HUNTER D54P SPECTROPHOTOMETER
        DIMENSION AV(6),AVGNO(4),CD(3,13),CMF(3,32),D65(32)
        DIMENSION NM1(5),NWL(32),PLAST(2)
        DIMENSION R(32,10),RC(32,13,2),RS(32),SPL(4,5),ST(6)
        DIMENSION STAR(3,13,2),TRI(3,13,2),TRIO(3),VAL(3)
        DATA CMF/0.0191,0.0020,0.0860,0.0847,0.0038,0.3894
     -,0.2045,0.0214,0.9725,0.3147,0.0387,1.5535
     -,0.3337,0.0621,1.9673,0.3707,0.0895,1.9948
     -,0.3023,0.1282,1.7454,0.1956,0.1852,1.3176
     -,0.0805,0.2535,0.7721,0.0162,0.3391,0.4153
     -,0.0038,0.4608,0.2185,0.0375,0.6067,0.1120
     -,0.1177,0.7618,0.0607,0.2365,0.8752,0.0305
     -,0.3768,0.9620,0.0137,0.5298,0.9918,0.0040
     -,0.7052,0.9973,0.0000,0.8787,0.9556,0.0000
     -,1.0142,0.8689,0.0000,1.1185,0.7774,0.0000
     -,1.1240,0.6583,0.0000,1.0305,0.5280,0.0000
     -,0.8563,0.3981,0.0000,0.6475,0.2835,0.0000
     -,0.4316,0.1793,0.0000,0.2683,0.1076,0.0000
     -,0.1526,0.0603,0.0000,0.0813,0.0318,0.0000
     -,0.0409,0.0159,0.0000,0.0199,0.0077,0.0000
     -,0.0026,0.0037,0.0000,0.0046,0.0018,0.0000/
        DATA D65/828.,916.,935.,868.,1049.,1171.,1178.,1149.,1159.,1088.,
     -1094.,1078.,1049.,1077.,1044.,1040.,1000.,964.,957.,886.,
     -900.,896.,876.,833.,837.,800.,802.,822.,783.,697.,716.,743./
        DATA SPL/'AMBE','R FI','LTER','    ',
     -          'WHIT','E TI','LE  ','    ',
     -          'GRAY',' POR','CELA','IN  ',
     -          'STD ','TAN ','PLAS','TIC ',
     -          'SPL ','TAN ','PLAS','TIC '/
        DATA AVGNO,PLAST/'ONE ','AV2 ','AV10','SIG ','STD ','SPL '/
C   1=AMBER@420;2=AMBER@520;3=AMBER@660;4=OPAL@540;5=GRAY@540;6=COL DIFF.
        DATA ST/3.48,38.68,80.20,98.36,42.96,1.88/
        DATA AV/0.03,0.18,0.12,0.10,0.10,0.05/
        DATA NM1/420,520,660,540,540/
100     FORMAT(' DATE: ',I2,2('/',I2))
120     FORMAT(// 1. ON D54 PRESS "ASCII OUT", THEN "0", THEN "TRAP"'/
     -'        PUT WHITE PORCELAIN OVER PORT,'/
     -'        BLOCK BEAM WITH BLACK CARDBOARD'/
     -' 2. PRESS "ZERO". REMOVE CARDBOARD'/
     -' 3. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54'/
     -' 4. PRESS "ASCII", THEN "2",'/
     -' 5. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER')
150     FORMAT(' BEGIN WITH SAMPLE NO.? (1-5)')
170     FORMAT(//'*** REMOVE AMBER FILTER***'/
     -' 1. ON D54, PRESS "ASCII",THEN "0",THEN "R-SIN"'/
     -'        PUT ZERO TRAP OVER PORT'/
     -' 2. PRESS "ZERO". PUT WHITE PORCELAIN OVER PORT'/
     -' 3. PRESS "STDZ". PUT GRAY PORCELAIN OVER PORT'/
     -' 4. PRESS "STDZ". AFTER "STANDARDIZED" PRINTS OUT ON D54,'/
     -' 5. PRESS "ASCII", THEN "2"'/
     -' 6. PRESS "RETURN" ON SPC-16 CONSOLE PRINTER')
200     FORMAT(// MEASURE: '4A4' INSERT SAMPLE IN D54:'/
```

```
     -'    AFTER A PAUSE IS PRINTED, PRESS "READ" ON D54'/
     -'    AFTER BELL RINGS, PRESS "10NM" AND "RETURN" AT SAME TIME')
210    FORMAT(//'***READING AT'I5'NM IS OUT OF SPECS FOR:'4A4/
     -'      WASH SAMPLE, THEN')
220    FORMAT(' AT',I4,' NM UPPER LIMIT',F6.2,' LOWER LIMIT',F6.2)
230    FORMAT(' COLOR DIFFERENCE: UPPER LIMIT'F6.2' LOWER LIMIT'F6.2)
240    FORMAT(//'*** COLOR DIFFERENCE IS OUT OF SPECS FOR: ',4A4/
     -'      WASH TILES, THEN')
250    FORMAT(V)
300    FORMAT(I5,3F10.2,F10.3)
350    FORMAT(I3,F11.2)
450    FORMAT(/2(2XA4),' X=',F7.5,' Y=',F7.5,' Z=',F7.5)
500    FORMAT(' W/L',5X,'FIRST',4X,'AVG OF 2')
700    FORMAT(/A4,' DL=',F7.2,' DC=',F7.2,' DE=',F7.2)
800    FORMAT(///'***OK TO MAKE MEASUREMENTS***')
       CALL FREMAT
       CALL DATE$B(IY,IM,ID)
       WRITE(5,100) IM,ID,IY
       WRITE(5,150)
       READ(5,250) NSAM
       IF(NSAM.GT.1) GOTO 950
       WRITE(5,120)
       PAUSE
950    DO 2000 II=1,5
       IF(II.LT.NSAM) GOTO 2000
960    I=II
       IF(I.NE.2) GOTO 970
       WRITE(5,170)
       PAUSE
970    WRITE(5,200) (SPL(M,I),M=1,4)
       K=1
       IF(I.NE.1) K=I+2
       IF(I.EQ.5) GOTO 978
975    UL=ST(K)+AV(K)
       OW=ST(K)-AV(K)
       IF(I.EQ.4) WRITE(5,230) UL,OW
       IF(I.EQ.4) GOTO 978
       WRITE(5,220) NM1(K),UL,OW
       IF(I.NE.1) GOTO 978
       IF(K.EQ.3) GOTO 978
       K=K+1
       GOTO 975
978    CONTINUE
       DO 1000 N=1,2
       PAUSE
       DO 980 L=1,32
       R(L,N)=RG(L)
       READ(14,350) NWL(L),RG(L)
980    CONTINUE
       DO 985 L=1,32
       R(L,N)=RG(L)
985    CONTINUE
1000   CONTINUE
       IF(I.LT.4) WRITE(5,500)
```

```
      K=1
      IF(I.NE.1) K=I+2
1100  DO 1140 L=1,32
      VAL(2)=0.
      DO1120 N=1,2
      IF(N.EQ.1) VAL(1)=R(L,N)
      IF(N.EQ.1.AND.I.GE.4) RC(L,1,I-3)=VAL(1)
      IF(N.LE.2) VAL(2)=R(L,N)*0.5+VAL(2)
      IF(N.EQ.2.AND.I.GE.4) RC(L,2,I-3)=VAL(2)
1120  CONTINUE
      IF(I.GE.4) GOTO 1140
      NM=390+L*10
      IF(NM.NE.NM1(K)) GOTO 1140
      WRITE(5,300) NM,(VAL(M),M=1,2)
      IF(ABS(VAL(2)-ST(K)).LT.AV(K)) GOTO 1135
      WRITE(5,210) NM1(K),(SPL(M,I),M=1,4)
      GOTO 970
1135  IF(I.EQ.1.AND.K.LT.3) K=K+1
1140  CONTINUE
2000  CONTINUE
C     I IS THE TRISTIMULUS COUNTER
C     J IS THE AVERAGES COUNTER
C     K IS THE SAMPLE NUMBER OF THE PLASTIC CHIPS COUNTER
C     L IS THE WAVELENGTH COUNTER
      DO 2900 I=1,3
      TRIO(I)=0.
      DO 2900 L=1,32
2900  TRIO(I)=TRIO(I)+100.*CMF(I,L)*D65(L)
      TH=1./3.
      DO 3070 K=1,2
      DO 3070 J=1,2
      DO 3020 I=1,3
      TRI(I,J,K)=0.
      DO 3000 L=1,32
      TRI(I,J,K)=TRI(I,J,K)+RC(L,J,K)*CMF(I,L)*D65(L)
3000  CONTINUE
3020  TRI(I,J,K)=TRI(I,J,K)/TRIO(I)
C     WRITE(5,450) PLAST(K),AVGNO(J),(TRI(M,J,K),M=1,3)
3070  CONTINUE
      DO 3080 I=1,3
      DO 3080 J=1,2
      DO 3080 K=1,2
3080  TRI(I,J,K)=TRI(I,J,K)**TH
      DO 3170 K=1,2
      DO 3170 J=1,2
      STAR(1,J,K)=116.0*TRI(2,J,K)-16.0
      STAR(2,J,K)=500.*(TRI(1,J,K)-TRI(2,J,K))
      STAR(3,J,K)=200.*(TRI(2,J,K)-TRI(3,J,K))
3170  CONTINUE
3180  DO 3250 J=1,2
      DO 3200 I=1,3
3200  STAR(I,J,1)=(STAR(I,J,2)-STAR(I,J,1))*(STAR(I,J,2)-STAR(I,J,1))
      CD(1,J)=SQRT(STAR(1,J,1))
      CD(2,J)=SQRT(STAR(2,J,1)*STAR(2,J,1)+STAR(3,J,1)*STAR(3,J,1))
```

```
      CD(3,J)=SQRT(CD(1,J)*CD(1,J)+CD(2,J)*CD(2,J))
      WRITE(5,700) AVGNO(J),(CD(M,J),M=1,3)
3250  CONTINUE
      IF(ABS(CD(3,2)-ST(6)).LT.AV(6)) GOTO 3300
      NSAM=4
      WRITE(5,240) (SPL(M,4),M=1,4)
      GOTO 950
3300  WRITE(5,800)
4000  STOP
      END
?
```